International cooperation: coproduction

program phases. Some of the more important considerations were:

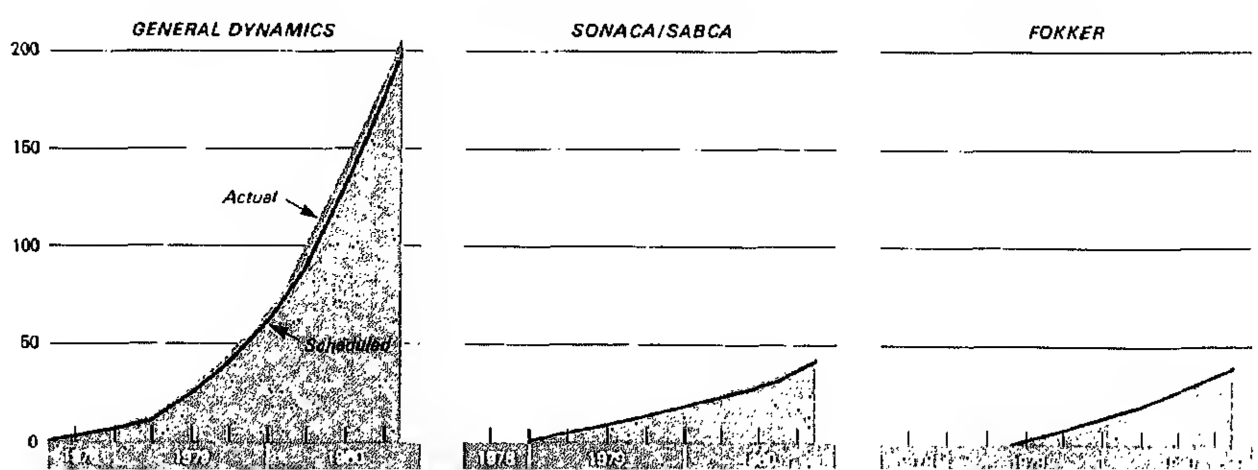
- **Early delivery requirements.** Dutch and Belgian plans for early replacement of their aging F-104G aircraft increased the pace of the program.
- **Start-up delays.** Resolving differences in acquisition procedures, finding qualified contractors, and negotiating the division of work all delayed start-up.
- **Longer lead times.** European work force policies discouraging surges in labor contributed to longer lead times for European parts. The longer lead times pushed the United States to an earlier-than-usual production decision, causing considerable development and production concurrency in the schedule. Also, the differences in lead times impeded incorporation of changes and complicated scheduling for final assembly.

The program's ambitious pace—as dictated by the early delivery requirements—coupled with European production start-up delays and work-force policy constraints, forced U.S. contractors to alter their production schedules. To keep initial deliveries on schedule, U.S. firms had to supply additional parts and subassemblies to European manufacturers. General Dynamics, for example, accelerated its tooling schedule and dipped into its management reserve to produce some aft fuselages originally scheduled to be produced by a Belgian firm that ran into financial difficulties. In effect, the ability of U.S. manufacturers to produce each aircraft component provided insurance against disruptions in the flow of components from European contractors.

Figure 2 summarizes F-16 schedule experience during the early stages of production. Although coproduction has made scheduling more complex, the combined efforts of U.S. and European producers prevented program delays that have marred a number of purely European collaborative efforts. Moreover, the F-16 production schedule and funding profiles have been significantly more stable than those of typical domestic programs, a feature due largely to congressional and DoD recognition of the extensive commitments made by the producing nations.

There is no simple answer to the question of whether collaborative programs cost more. The cost implications of any program are very complex and depend critically on the participants, the product, and the

Figure 2. Summary of F-16 schedule experience during the early phases of coproduction



view, which is actually a composite of Air Force, DoD, and U.S. government perspectives, the F-16 program has had a generally favorable cost outcome for a coproduction effort.

Coproduction of the first 650 U.S. F-16s is expected to increase costs to the Air Force by about $170 million (in 1975 dollars), approximately 5 percent of total program expenditures. Estimates indicate that coproduced items are likely to cost the Air Force more than the same items produced domestically, because of the higher cost of subcontracting in Europe (see Figure 3). But sale of F-16s to the Europeans also led to a larger production volume for most U.S. contractors, thus offsetting some of the additional costs incurred by the Air Force.

In meeting the European requirement for F-16 airframes, for example, General Dynamics manufactured the equivalent of 144 airframes over and above the 650 airframes it produced for the U.S. Air Force. This increased volume benefited the traditional manufacturing learning curve and therefore this increased volume yielded significant savings in labor costs as well. Moreover, Air Force programs requiring the same equipment or components used in the F-16 benefit from savings due to increased volume as well. The F-15 program, which uses the same F-100 engine that powers the F-16, is one example.

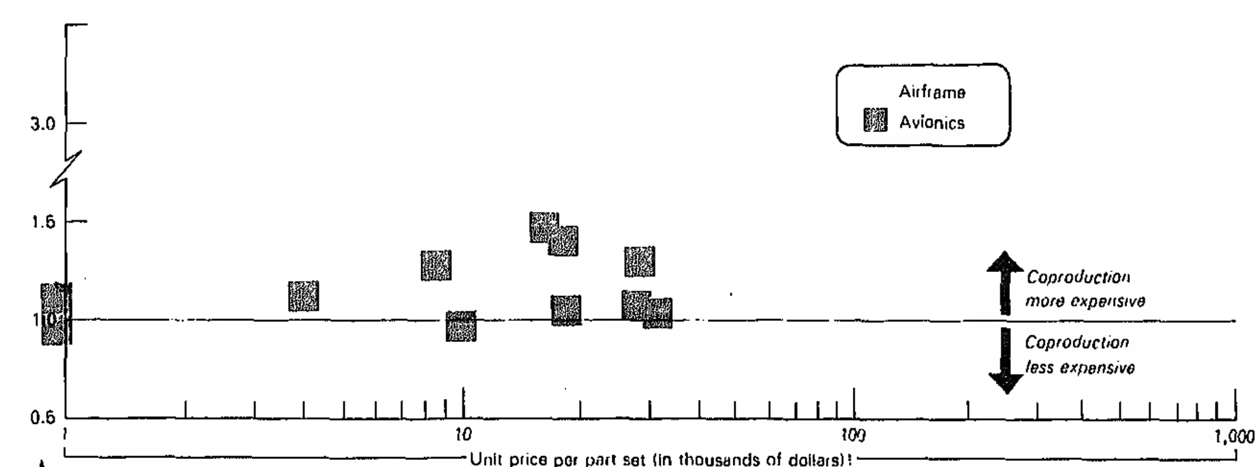
Expanded volume can also lower overhead costs at U.S. production plants, thus potentially lowering fur-

ings achieved at F-16 plants to other DoD production efforts at those same facilities. Like the Defense Department, the U.S. government reaps benefits from F-16 coproduction too. The U.S. Treasury is receiving $163.5 million (in 1975 dollars) from participating European governments for research and development fees, and the increase in European sales translates into additional U.S. tax revenues.

This quantitative focus on costs is of course too narrow. It ignores hard-to-quantify but significant benefits such as NATO standardization and improved European management, manufacturing, and maintenance capabilities. In fact, assessing coproduction cost implications from the European point of view even more strongly demonstrates the importance of perspective and nonquantifiable benefits in the total cost equation.

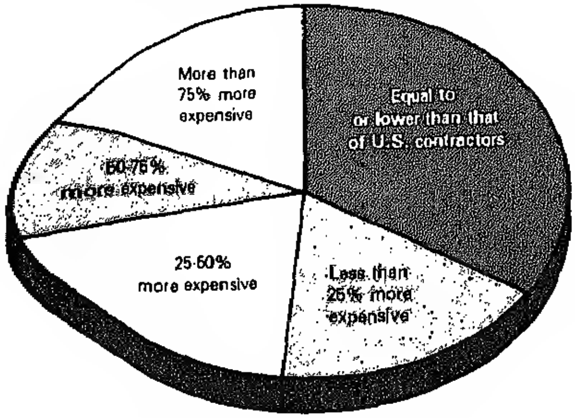
The participating European governments could have purchased their collective requirement of 348 F-16s directly from General Dynamics. By choosing coproduction over direct purchase, they appear to have accepted a 34-percent cost penalty. But such a strictly monetary comparison ignores many other important factors that color European thinking on the costs and benefits of coproduction. Specifically, collaborative programs offer opportunities for industry capitalization, development of an indigenous aircraft support capability, technology transfer, employment stability or growth, improved political relationships and military

Figure 3. Estimated effect of coproduction on the cost to the Air Force of selected airframe and avionics part sets



* RATIO OF THE AVERAGE PRICE OF A 998 AIRCRAFT COPRODUCTION PROGRAM TO THAT OF A HYPOTHETICAL 650 AIRCRAFT DOMESTIC PROGRAM (IN 1975 DOLLARS)
† AVERAGE PRICE OF A HYPOTHETICAL 650 AIRCRAFT DOMESTIC PROGRAM (IN 1975 DOLLARS)

and avionics contractors in the F-16 program



NOTE: PRICES FOR EQUAL QUANTITIES AND NO ADMINISTRATIVE LOADINGS

capability, standardization, and cost recovery of domestic spending through taxes.

From the European perspective, a realistic evaluation of the F-16 program must address more than incremental increases in program costs due to the coproduction arrangement. Eloquent proof of that assertion is Belgium's decision to supplement its initial F-16 procurement by building 44 additional F-16s domestically rather than purchasing them directly off the U.S. production line. Belgian officials admit that direct purchase would be about 10 percent cheaper. However, domestic production of the F-16s will provide Belgian jobs for at least ten years and secure orders worth the equivalent of about $472 million for Belgian industry. The government of Belgium estimates that it can recover nearly $180 million in taxes from these sales. Thus, on net, the country will save about $106 million by opting for domestic production over direct purchase. And that figure does not reflect savings in unemployment benefits that would otherwise have to be paid to jobless aerospace workers.

The cost comparisons made so far have not been adjusted for differences in quantities produced or for costs charged by a prime contractor to administer subcontracts. Figure 4 depicts the theoretical relative price competitiveness of European and U.S. contractors for selected F-16 aircraft and avionics part sets when price is adjusted for these factors. As the figure indicates, European prices are competitive with U.S. prices for only about one-third of the part sets in the sample. Constrained by a not-to-exceed cost target and by pressures

come the cost compe... the strengths of European industry, structuring work packages that exploited those strengths, and using volume production to bring down costs.

To the extent that it can serve as a paradigm for assessing the costs and benefits of collaborative programs, the F-16 program suggests some guidelines for lessening the inherent difficulties of collaboration. In particular, managers of coproduced weapon systems should:

- Recognize differences in U.S. and European acquisition settings and environments and plan accordingly.
- Exploit unique U.S. and European industrial capabilities as well as U.S. advantages in scale, work force flexibility, and production redundancy in order to cope with program diversity.
- Involve foreign producers as early as possible in order to facilitate technology transfer.
- Use quantity production to reduce the costs of less efficient coproducers.

As these highlights of Rand's research efforts make clear, multinational coproduction of a major weapon system is a delicate and complex undertaking, the outcome of which is largely determined by the distinctive capabilities and industrial milieu of each participant. While the above guidelines are hardly an inclusive, surefire formula for success, they do nonetheless represent a solid point of departure. DMJ

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Countertrade, technology transfer, and international defense sales

By DALE W. CHURCH

Expansion of the world's defense industrial base and a greater reliance on countertrade arrangements suggest that the time may be ripe for rethinking our approach to international defense sales.

The nature of international defense sales is changing rapidly, and the transformation is raising troublesome questions concerning the security of the free world. A major catalyst in this process is the sharply stepped-up pace of military production among developing countries; countertrade and technology transfer are significant factors as well. The discussion that follows will explore these issues and propose a response to the challenges they pose.

Many western nations have long enjoyed the fruits of advanced technology and a vibrant defense industry. In recent years, numerous developing countries have made a bid to join their ranks. Brazil, South Korea, Israel, India, South Africa, Chile, and Argentina have all made great strides, and Egypt, Pakistan, Singapore, the People's Republic of China, and Taiwan have realized significant gains, too. In addition, Japan has tremendous opportunity to expand its defense industry by applying sophisticated Japanese commercial technology already in place.

Even now, these countries produce a wide variety of military systems, ranging from small arms and ammunition to armored vehicles, guided missiles, and fighter aircraft. Of the nations mentioned, eight can produce armored vehicles, nine can produce missiles, and sixteen can produce fighter aircraft. In all, some 25 countries have shipbuilding capabilities.

supply interruptions during time of conflict, and improved operations and maintenance capabilities.

While these are strong motivations, most developing countries continue to experience shortages of financial resources and of skilled engineers and technicians, particularly in electronics. Development of an indigenous defense industry tends to proceed in six stages, each marked by a greater degree of independence from foreign assistance:

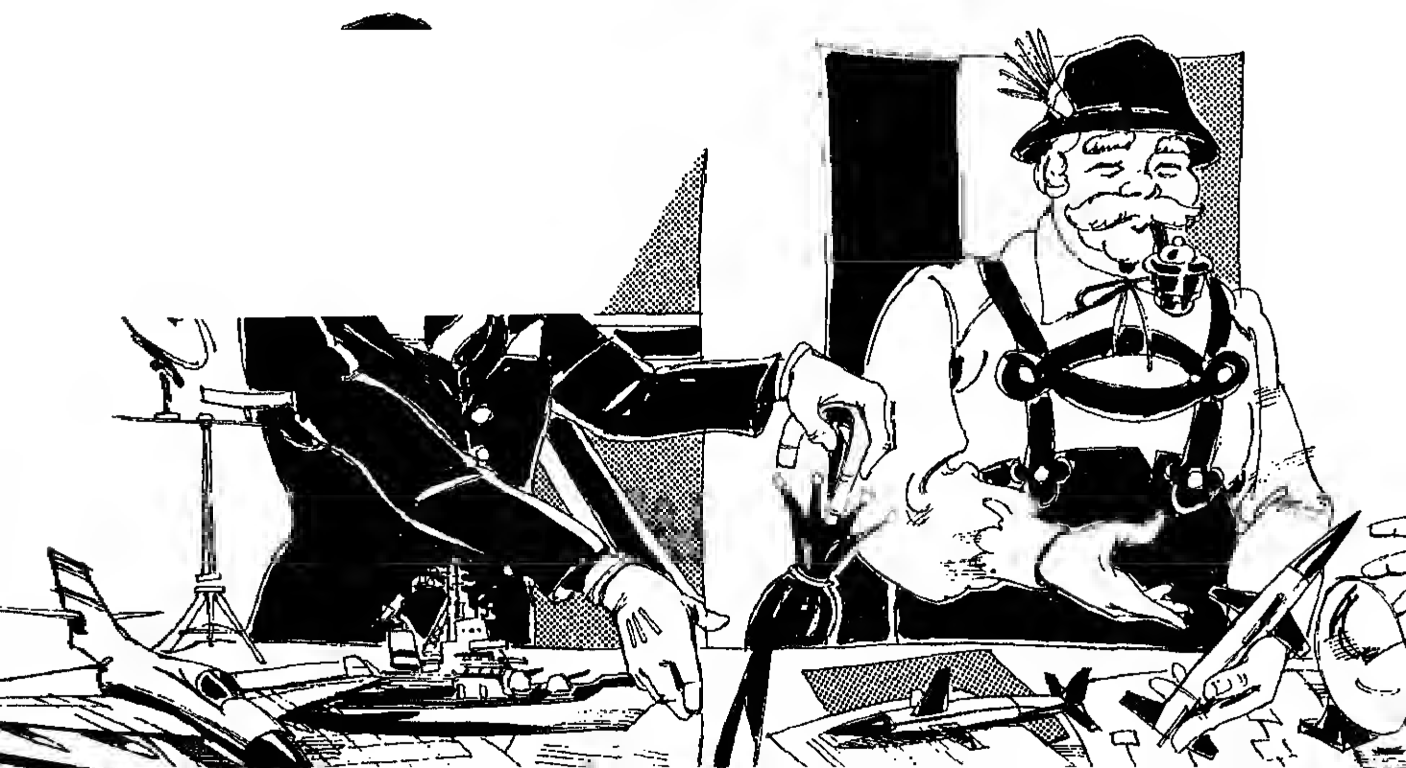
- Maintenance and repair of imported systems.
- Assembly of subsystems from wholly imported components.
- Final assembly of imported components.
- Complete local production of components and assembly using those components.
- Production using imported designs (with minor modifications) or production through reverse engineering of foreign weapons.
- Production based on local research and design of new systems.

Very few developing countries are yet at the sixth stage; several, however, have reached the one immediately before it in varying degrees. Interestingly, countries are marketing weapons throughout the world as wholly domestic systems, even though the product is

Why the emphasis on defense industries? The motivations are economic and political as well as military. Economically, domestic production of weapons may reduce acquisition costs for those systems, promote technological development within the country, boost export earnings, and improve both the balance of payments and the skills of the native work force.

Political or social considerations, if less tangible, are no less real. Principal among them are national pride in native industrial capability and a more stable relationship between the country's political and military elements. And obviously, an indigenous defense industry

ILLUSTRATION BY RALPH BUTLER



to this stratagem as a means of circumventing licensing restrictions, imposed by either the U.S. government or private firms, that would otherwise apply. Such restrictions typically affect sales to third-world nations.

While the defense industrialization of developing countries does not usually pose an immediate threat or challenge to industrialized states, it still concerns them because it directly affects the approach that less developed countries are taking to all their defense requirements. In the case of imported systems, this approach often involves countertrade and significant technology transfer that has both commercial and military implications. Before agreeing to such sales, therefore, the United States must examine the motivations and intentions of the buying countries.

Without some form of countertrade, we will conclude few major arms sales to developing countries in the future. Because they already lack sufficient foreign exchange to enable them to pay with hard currency, these nations must use credits, goods, or a combination of the two to pay for their purchases. The trend among them has been to buy expensive higher technology weapon systems; at the same time, credits have declined overall and have been concentrated heavily in only a few countries such as Israel and Egypt. Even those few countries have tried to pay with bartered goods. But most of them have little in the way of marketable goods to trade for their defense purchases. Instead, developing countries must look primarily to direct offsets, or countertrade, in which they participate by supplying part of the purchased system, manufactured or assembled domestically, to cover part of the cost. Because less developed nations have little industrial base, countertrade requires very substantial technology transfer to enable the purchaser to do the offset work.

The buyer's major concern is to have the technology transferred to him as soon as possible. Interim steps include early establishment of indigenous capability for servicing, assembly, and component manufacturing. The importer's ultimate goal is complete domestic production of the defense systems being negotiated.

The selling country, on the other hand, needs to address a series of issues when the buyer demands technology transfer along with the product. In 1978, the United States government established a position against becoming directly involved in offset arrangements either as participant or guarantor. However, because the government must approve sales involving technology transfer by U.S. industry, it cannot avoid examining the key transfer issues.

In particular, policy-makers must ask:

• Will transfer of the technology in question enhance the recipient's relationship with the U.S.?

• From the perspective of both U.S. industry and friends and allies of the United States, what are the short- and long-term implications of establishing new capacity in a particular country?

• Does the transaction make sense economically, or will the costs of producing locally so increase overall costs as to make the deal self-defeating?

• Will potential adversaries have access to the technology? Will the transferee imitate it?

• Does the purchaser genuinely need the technology, or is offset merely a ploy to obtain the technology for purposes other than defense?

• Can the buyer's needs be met without giving him all the technology?

• What impact will the transfer have on the U.S. technological base?

In sum, the supplying country's task is no longer simply providing the system. The seller must also assess the buyer's capabilities and carefully consider his countertrade or offset needs. The transaction must not only be satisfactory to the buyer and within his capabilities, but also consistent with the best interests of all concerned parties. This task is complex and needs to be approached, if not as an art, then at least artfully.

Beyond the technology transfer question lies a more basic one. Should the United States government become more involved in countertrade programs at all? Recent studies by the Defense Science Board and the Defense Policy Advisory Council on Trade report concern among many of our allies, including the North Atlantic Treaty Organization, over further increases in what is already excess capacity in the world's defense industries. Offset programs clearly accelerate this growth.

Most countries purchasing weapon systems now require that at least 30 percent of the sales price be offset

sisting upon offsets both in foreign military sales, which involve the Defense Department as agent, and in direct sales between buyer and seller. Recent purchases of the F-18 aircraft by Australia and Canada, for example, included multi-billion dollar offset commitments, direct and indirect. Australia used foreign military sales channels; Canada bought directly.

A new investment offset is the forthcoming C3 Peace Shield program for Saudi Arabia. It requires that bidders agree to invest 35 percent of the value of the sale in that kingdom. As a result, the Saudis will realize investments of more than a billion dollars in new industrial capacity in their country.

Initially, commitments under such programs were on a "best effort" basis. However, as the buying nations became more sophisticated, they established penalties for failure to fulfill offset commitments on time. At one extreme, Indonesia has imposed a penalty of 50 percent, payable in hard currency, on the amount of any shortfall. Even major buyers such as Israel are requiring a 10 percent penalty against shortfalls. Penalties, of course, are a source of additional funds to further expand the defense industrial base.

Nations appear to agree that the increase in the world's defense capacity is a major problem over and beyond concerns about technological competitiveness. Once capacity is created, it requires justification in terms of production for in-country needs or export sales, or both. In many current hostilities, the arms suppliers are neither U.S. nor European. Clearly, it follows that as the world's defense industrial base increases, so will the supply of arms.

But while everyone seems to agree there is a problem, no one seems to have a solution. U.S. companies cannot even agree with each other on the extent that the federal government should participate in controlling offsets. If U.S. interests cannot agree among themselves, can we realistically expect our allies to control offsets, particularly when a U.S. company is competing with one of their own? Yet something must be done.

If no easy solution is at hand, we nonetheless can take steps to alleviate the situation. Implementing such measures requires recognition of three key premises:

• All nations of the world must have the ability to protect their national sovereignty; in other words, they must have a defense capability at least commensurate with the apparent threat to their territory.

• Few, if any, nations of the world can pay cash for weapons they need; even those who can, have legitimate concerns about the impact of such outlays on their foreign trade balances.

ticipate economically in sales to their country and will find a means to assure that they do.

With these points in mind, how can we restructure the current approach to defense sales to accommodate such transactions and yet avoid creating additional and unnecessary capacity? The first step is acknowledging a country's need to be able to maintain and repair its defense systems internally. Selling nations must be willing to supply sufficient technological and technical assistance to fulfill this need. Admittedly, with such assistance, the purchaser may eventually be able to produce the systems domestically, but in most cases local demand will not justify the additional investment required for production.

Moreover, refusing to transfer the technology poses its own dangers. For if the buyer concludes that the supplier does not trust him, he is not likely to have confidence in the supplier's willlingness to provide spares and other support in time of crisis or actual conflict. The buying country thus confronts a difficult choice. It can either make the investment to become self-sufficient and eventually be able to produce and develop its own weapons, or it can leave itself vulnerable to a supplier who may not support the country during times of threat or conflict. If enabled to repair and maintain its defense systems domestically and if guaranteed enough spares to meet territorial defense requirements, the country need not face this choice.

A revamped approach to defense sales must also accommodate the need of buying countries to barter in order to execute such sales. Because most countries are acutely short of foreign exchange and heavily burdened with debt, "trade, not aid" is a necessity today. More often than not, these bartered goods will not be sufficient to pay for the defense systems, and we will also have to help nations improve both the supply base and the quality of the goods offered for trade.

However, even these steps are not likely to be enough. Credits must be offered as well, and the length of the loan and level of interest must be realistic. A recent General Accounting Office report called for 30-year credits with liberal repayment terms. The rationale for such loans is simple. The more defense systems a country can afford to buy, the less likely it will produce its own. Moreover, long-term defense credits allow a country to emphasize the nondefense sectors of its industrial base.

Some will argue that credits encourage nations to buy more arms than they would otherwise. But that objection is beside the point. Recent experience has shown that countries will obtain the arms they want somewhere, even at e expense of the nation's econom and

it has hurt U.S. industry. The United States must recognize that nations will find a way to meet perceived defense needs and that it is far better that they turn to the free world to do so.

Finally, rethinking our approach to defense sales requires that the United States come to terms with the longstanding role of agents in defense trade. Following a period of self-criticism, the U.S. reacted strongly to abuses in the agent system which had led to the corruption of foreign officials. Our response included stringent remedial measures such as the Foreign Corrupt Practices Act and an administrative decision to put a $50,000 ceiling on agents' fees.

The limitation on fees in effect eliminated the commission per se, but also forced agents to create new techniques—offsets and subcontracts, for example—in order to maintain their business interests. Allowing agents a reasonable fee for their efforts would dampen, if not eliminate, their demand for offsets, and immediate action is in order to permit such fees on defense sales. The Foreign Corrupt Practices Act is adequate to control any abuses.

To resolve legitimate concerns over technology transfer and countertrade in defense sales, the United States needs to be confident that it can replenish its own reservoir of technological capital in order to retain technological leadership. The only way to achieve such an objective is to make technological superiority the cornerstone of our national security strategy. Achieving and maintaining clear superiority in civil and military technology must be a national goal, and we must make sufficient investments in research and development to attain this goal. Then we can proceed with industrial collaboration with our friends and allies. DMJ

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on civil emergency plans

By LOUIS O. GIUFFRIDA

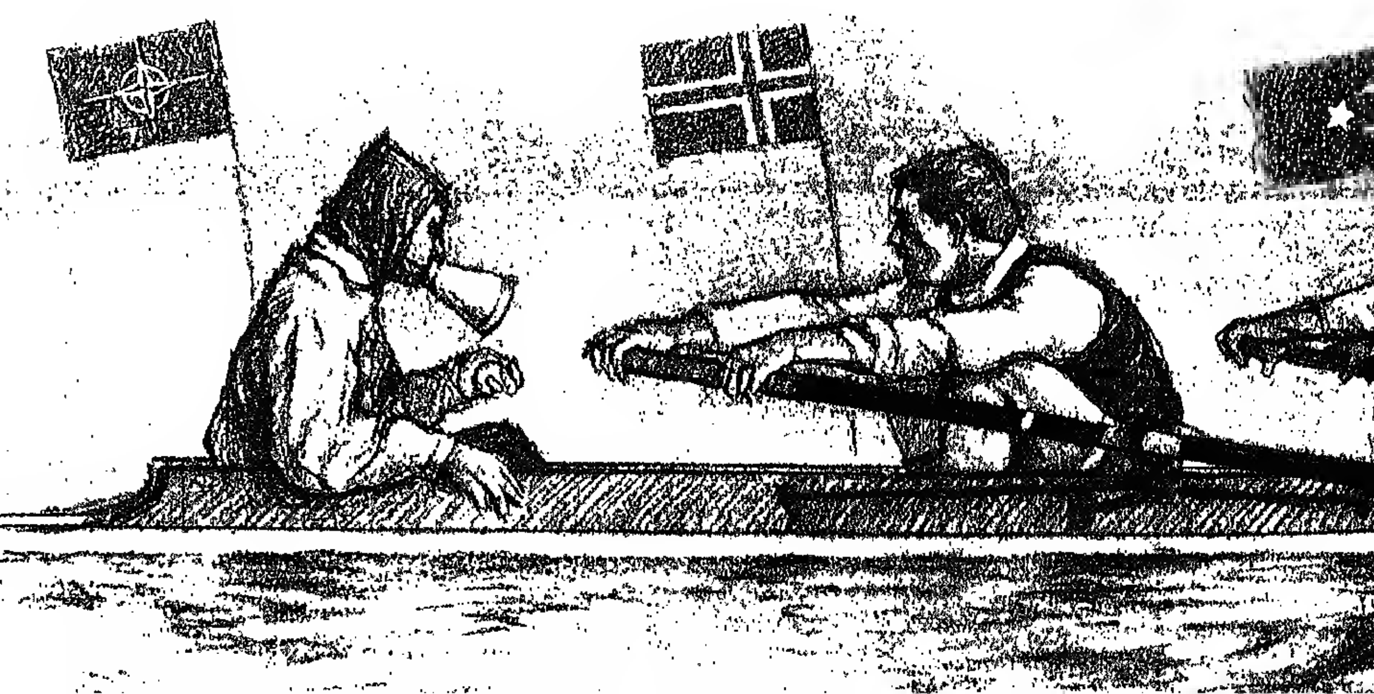
Although historically an internal matter, the responsibility for devising an effective civilian emergency-response plan has outgrown national boundary lines.

Charged with preparing for and responding to national emergencies and war, the Federal Emergency Management Agency brings life to the adage that a day of preparation is worth a month of reparation. Domestically, the agency's civil preparedness mission is twofold. First, it must ensure that the U.S. civil sector can respond rapidly and effectively to war and other national or major peacetime emergencies. Secondly, it must develop plans and programs to protect the citizenry in such eventualities.

But FEMA's efforts are not confined within the nation's borders. In fact, the agency works very closely with civil preparedness elements in other NATO countries. For just as the U.S. Defense and State Departments have their counterparts in NATO, so too does FEMA.

The NATO Senior Civil Emergency Planning

ILLUSTRATION BY WILLIAM C. REYNOLDS



director of the Federal Emergency Management Agency consults and coordinates with officials of various agencies and executive departments in order to formulate the U.S. role and coordinate our nation's contribution to civil emergency planning within NATO.

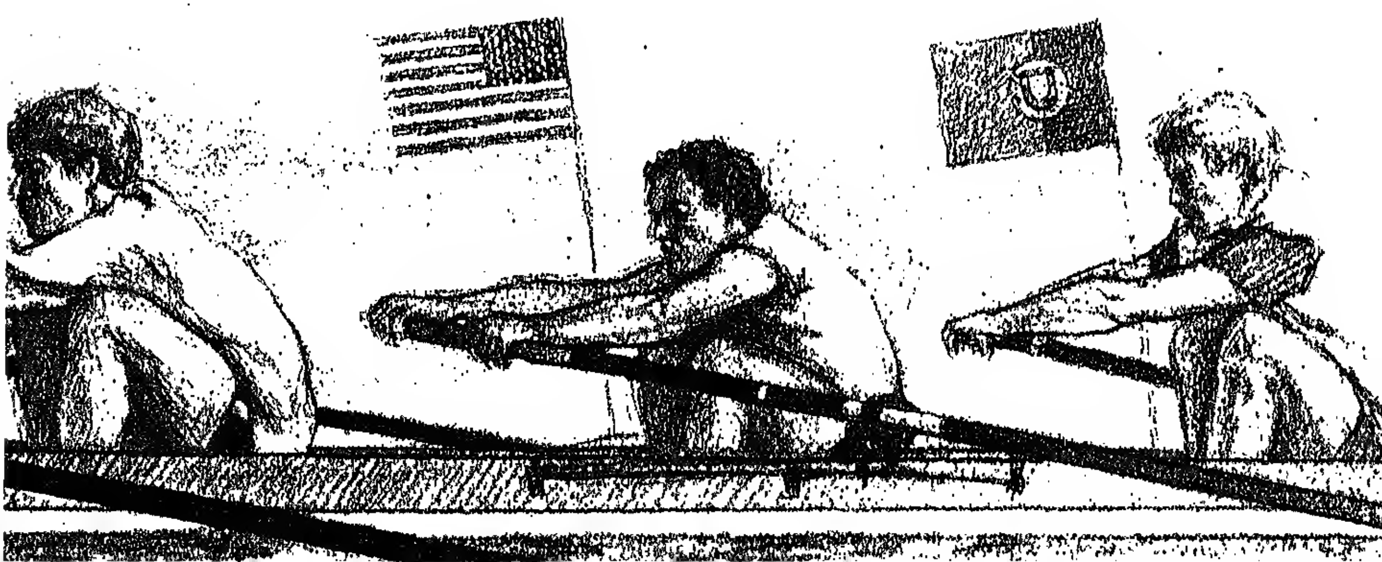
The emergency planning committee monitors the work of eight subordinate planning boards and committees and more than 40 other planning elements and work groups. FEMA ensures U.S. representation on each of these bodies, which address specific functional areas ranging from civil aviation to food and agriculture. In addition, FEMA assigns a senior staff officer to our NATO mission in Brussels; that individual advises the U.S. ambassador on civil emergency planning.

NATO nations generally agree that the allies need to draw up a coordinated civil preparedness blueprint, one that focuses on civil-sector support of military operations and protection of civil-sector capabilities. For the most part, the aims of the collective NATO effort parallel those of this nation's domestic program. These aims include maintaining the social and economic order of member nations, protecting and ensuring the survival of the citizenries, sustaining critical government operations, using available resources prudently, and rapidly

Most European NATO countries regard the U.S. approach to civil-military coordination as a good model for integrating peacetime crisis management with war emergency planning. They are particularly drawn to the pragmatism of treating preparation for natural and man-made disasters as a single management problem. But because of their geographical proximity to one another, European NATO nations face a particularly challenging coordination task. The difficulties derive not so much from the number of countries or working groups involved, but from the number and diversity of functional areas.

Unlike the United States, European countries must contend with such eventualities as the accelerated use of multinational inland waterways, roads, and railroads. They must also be prepared to handle stepped-up border crossings and the need for a sensible relaxation of traditional international protocol. In addition, developing a comprehensive plan raises many perplexing questions concerning the allocation, storage, and stockpiling of materials such as food, petroleum, and medical supplies.

Although these and other issues tend to impede rapid formulation of a program, the alliance is doing much to effectively integrate civil planning



with military capabilities. In transportation, for example, the Planning Board for European Inland Surface Transport is assessing the potential impact of recent European rail system realignments on emergency operations. The Civil Aviation Planning Committee is devising a plan for transport of ammunition by civil aircraft and for reception and storage of ammunition at civil airfields. This committee is also pursuing commitments from member nations to provide cargo-capable aircraft in support of rapid reinforcement, and it is identifying and minimizing the possible impact of problems likely to arise from heavy reinforcement traffic. Concerned about the continuing attrition of general cargo ships, the Planning Board for Ocean Shipping is encouraging each European NATO member to establish its own reserve fleet of cargo ships, similar to the U.S. National Defense Reserve Fleet.

Other critical areas are receiving attention as well. The Industrial Planning Committee, for instance, is determining both the maximum production rate at existing ammunition manufacturing facilities and the amount of time needed to achieve this rate during mobilization. And the Civil Communications Planning Committee is seeking an alliance-wide agreement on a recently drafted document outlining the use and control of international communications in crisis or war.

Though ongoing planning efforts largely concern the European theater, U.S. interest in and contributions to the program are significant. Thus FEMA has rejuvenated the U.S. Civil Emergency Planning Coordinating Committee in an effort to ensure complete domestic coordination on all NATO civil-preparedness issues. This multidisci-

ing of the NATO Planning Board and Committee, formulates a U.S. position on each agenda item, and identifies areas requiring particular international attention.

FEMA's efforts to establish a closer link between the civil and military sides of NATO are starting to yield results. For the first time ever, the NATO international military staff and the NATO international civil staff recently collaborated on an after-action report of a NATO exercise. In the wake of this combined effort, the conference of senior NATO logisticians and the Senior Civil Emergency Planning Committee agreed to work together to resolve lingering problems of coordination, procedure, and organization. FEMA has also submitted a recommendation to the Senior Civil Emergency Planning Committee calling for the NATO Defense College to adequately emphasize civil emergency planning and crisis management throughout its curriculum. Such emphasis would give military members a broader appreciation of civil crisis management within the alliance.

To improve civilian preparedness planning in 1984, the Federal Emergency Management Agency established goals for U.S. planning elements. The State Department published these objectives last December, marking the first time in recent years that the U.S. community has had formal groundwork on which to base its efforts. Major goals include:

- Regular coordination among U.S. departments and agencies in formulating policy positions.
- Improved coordination between various U.S. government agencies and their counterparts in NATO countries.
- Promulgation of more authoritative and definitive guidance from NATO's Senior Civil Emergency Planning Committee to the NATO planning boards.
- Development of a well-defined mission statement on the wartime role of that committee and its NATO headquarters staff.
- Expanded civil participation in NATO exercises.
- Commitments from NATO members to provide sufficient cargo and civil aircraft to satisfy reinforcement requirements in Europe.

These NATO-related efforts are only one facet

To promote fast and effective civil-sector response in time of war or national emergency, for instance, FEMA managers work closely with DoD in maintaining a system of resource stockpiles and in establishing production priorities. Also, the agency oversees and revises various programs designed to enable key federal agencies to operate during such crises.

Complementing the agency's work to sustain domestic industrial production and government operations are its efforts to protect and minister to the civilian population. In particular, FEMA officials are helping state and local governments design programs to shelter or evacuate residents in the event of war or peacetime disaster. The cornerstone of these programs is an extensive, modern, and redundant communications, data-processing, warning-issuance, and command center complex known as the FEMA National Emergency Management System. System personnel monitor potentially dangerous situations, identify those requiring attention, obtain information needed to develop a course of action, and direct state, local, and FEMA offices to respond.

The system consists of an emergency coordination center, located in Washington, D.C., an alternate headquarters center, and 10 regional command centers currently being modernized. Its sophisticated communications network links these centers with the White House, appropriate federal activities, and state emergency operations centers. In time of crisis, the complex permits continuous interaction with key federal and state authorities.

FEMA also supports state and local efforts to ensure that warning and protection measures extend to as many U.S. residents as possible. One way it does this is through direct financial assis-

FEMA's mission is to design a comprehensive framework that effectively integrates civil-sector mobilization, relief operations, recovery assistance, and hazard mitigation. The task is a difficult and complex one. It demands not only a proper blend of foresight and diligence, but a degree of coordination that now extends across the Atlantic.

emergency planning personnel and half the cost of necessary communications equipment. It also picks up the entire tab incurred by states and localities in developing geographically specific plans for various emergencies.

In addition, FEMA maintains the National Warning System, which alerts residents to forthcoming enemy attack, natural disasters, and manmade catastrophes. Concurrently, the agency seeks to ensure the continued operation of selected radio stations as components of the U.S. Emergency Broadcast System during such emergencies, principally by spearheading efforts both to provide them with radioactive fallout protection and emergency-power systems and to retrofit them so that they can withstand electromagnetic pulse commonly associated with nuclear detonation.

As the above discussion makes clear, FEMA's mission is to design a comprehensive framework that effectively integrates civil-sector mobilization, relief operations, recovery assistance, and hazard mitigation. The task is a difficult and complex one. It demands not only a proper blend of foresight and diligence, but a degree of coordination that now extends across the Atlantic. DMJ

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Leverage for logisticians in the decision-making process

By TODD E. STEVENSON,
KENNETH J. BREITBART,
and
BRETT A. CHRISTY

A just-published Army guide helps translate the impact of logistic shortfalls into real-world, easily understood terms that should give logisticians leverage in influencing weapon systems decision-making.

Decision-makers need information. More specifically, they need clear, concise indicators of the relative worth of alternatives at hand. For decisions involving logistics, the Army has developed a procedure to relate all of the various activities commonly known as logistic support to just such indicators. It has already proven valuable in allocating resources for support of the M1 tank and could well facilitate the unique decision-making effort that support of internationally deployed systems entails.

The document which outlines the Army's procedure is entitled *Integrated Logistic Support: Developmental Supportability Test and Evaluation Guide* (Department of the Army pamphlet 700-50). Its purpose is to help evaluators identify shortfalls in development of a logistic support system and then relate the shortfalls to easily understood indicators of operational availability and operating and support costs. Using these indicators, a decision-maker will be able to choose his course of action confident that he has a clearer picture of the long-term effects of his decision.

Applying the methodology called for in the recently published supportability test and evaluation guide, the Army critically appraised the test sets for the M1 Abrams based on dete

The decision-making process

The nature of the acquisition process underscores the need for clear-cut indicators of the impact of logistics considerations. In broadest terms, the Army's acquisition strategy, with its associated decision points, is a very recognizable purchasing procedure. The service identifies a need in a particular area, determines what technology can reasonably fulfill that need, develops and tests a prototype embodying the technology selected, and finally decides what system to produce for use in the field. This process requires answering two critical questions: "What technologies should we investigate to fulfill our need?" and "What should we produce?"

Such decisions are generally not simple "go" or "no-go" determinations. Rather, they tend to be choices among alternatives, such as "What course should I follow?" and "What areas need more work?" The decision-maker needs to know more than what the system can do (performance), what it costs this year (acquisition cost), and when he can have it (production schedule). To make an in-

New ILS guidance to aid decision-makers

time it will be available in a field environment and how much it will cost him to own it. Logistic supportability test and evaluation is beginning to provide the answers in these areas.

The acquisition strategy of the military services and that of private industry are similar in that both involve a decision to convert the chosen technology into a fully engineered, working model capable of being produced. In the Army, this decision point is milestone II and the production phase is full-scale development. The latter precedes milestone III, the decision point concerning what final configuration to place in production, and is also the high-visibility, work-intensive period during which most of the logistic support system is developed.

An awareness that all the facets of logistic support—tools, test equipment, manuals, spare parts, training, facilities, materials handling equipment, storage cases, and so forth—in fact constitute a system clarifies the nature of the acquisition process. That process actually results in two dependent systems. The first is the traditional end item, the tank, truck, or radio that performs the required function. The second is the entire set of support hardware, procedures, and personnel that keep the end item running properly, in other words, the logistic support system. The Army's guide, published on January 1, 1984, facilitates the planning process that enables program personnel to define the relationship between the two.

Planning for a decision

necessary facts are available for an informed decision. To provide that planning in the acquisition field, the Army has implemented an independent evaluation process. The responsible manager begins the process early in an acquisition phase by anticipating the questions that need to be answered at the end of the phase to support the upcoming decision. At the end of full-scale development for a truck, for example, the major decision is whether to produce the truck.

Making that decision in turn requires answers to other questions such as "Is the truck capable of carrying the intended cargo?" Anticipating this question early in the development phase allows analysts to develop a method for evaluating the issue and enables them to design tests for collecting the data needed to implement the evaluation method. By breaking down a large, sweeping decision into its component parts, the analysts can create evaluation methods for each part and then design tests that produce the data called for by the evaluation method.

The evaluation planning process applies equally well to system performance and logistic support. Thus, at the production decision point referred to above, the decision-maker must also ask himself, "Am I ready to produce the logistic support system?" and, if so, "What changes does it require?" If the logistic support system has shortfalls, the decision-maker needs to know where to apply available assets to get the highest increase in support for the dollars spent. A well-designed test and evaluation program can provide much of the information he needs. But how does one design and conduct such a program?

The test and evaluation guide

In 1979, the U.S. Army Materiel Development and Readiness Command began work on a structured method for designing the test and evaluation process for logistic support systems. The process was to be embodied in a guide that evaluators could use to assess the status of the logistic support system during each development phase. The guide was to be sufficiently broad in scope to allow virtually any staff element to perform as an evaluator, o icipate the desired outputs of logistic y tem

Activity and the U.S. Army Test and Evaluation Command accepted the task of developing the logistic supportability test and evaluation methodology.

The Developmental Supportability Test and Evaluation Guide published earlier this year sets forth that methodology and affects the test and evaluation documentation produced for all phases of the acquisition cycle. It constitutes a roadmap for writers of the independent evaluation plan, which in turn serves as a basis for the test design plan drawn up at each phase. These documents list the areas that need to be investigated and prescribe the methods analysts are to use in evaluating test results. They enable program personnel to compile the coordinated test program document (or test and evaluation master plan for larger systems), which, by regulation, must detail the plans for testing and evaluation to be conducted by the developmental tester, the operational tester, and the contractor.

The guide first takes up the independent evaluation plan and the test design plan, then describes the types of testing that can be conducted to produce the information needed to support the evaluation, and concludes with a discussion of the evaluation of logistic supportability for milestone decisions. It categorizes support for the system being acquired into the familiar integrated logistic support elements and devotes a chapter to each element. The chapters suggest evaluation issues; methods to carry out the evaluation; and data items to collect, by means of tests or analyses, in order to implement the evaluation methods.

What's more, the guide recognizes the need for a common, coordinating thread that relates all the elements of logistic support in a way useful to decision-makers. The unifying factors selected are to reflect the contribution of each element to the overall worth of the support system. They should also measure shortfalls against meaningful criteria that can influence decision-makers to commit funds and manpower to resolve the problems.

The authors of the guide chose two unifying factors for evaluation of logistic supportability: operational availability and operating and support costs. The former is a measure of the impact of logistic support shortfalls on the capability of the

tools or inaccurate test equipment result in weapons not being available to the commander in the field.

Operating and support costs, on the other hand, are a gauge of the business aspects of acquiring and owning a weapon system. If a particular logistic shortfall translates into a 10 or 20 percent increase in operating and support costs, a decision-maker can better judge whether to apply corrective measures now or live with higher costs throughout the life of the system.

Relating each element of logistic support to both operating and support costs and operational availability requires complex and intensive planning. The Army's supportability test and evaluation guide in effect prompts planners to structure an evaluation which covers all elements of logistic support for a particular weapon system.

An example of a complete evaluation of logistic supportability in the manner described by the guide would be overly cumbersome. But the following composite example, taken from a report on the Abrams M1 tank and from an analysis performed after the M1 was fielded, adequately illustrates application of the methodology to one area of the logistic support system for a rather large acquisition program. It also clearly demonstrates the benefits that can accrue.

M1 test sets—the method applied

The performance of test sets during development test II of the M1 Abrams showed that the sets necessary for diagnosing malfunctions were critical to overall logistic support, due in large measure to the complexity of the subsystems that must work together to realize the astounding potential of the M1. The test sets became particular subjects for investigation during development test III, the milestone immediately preceding the production decision. Testing personnel first collected data on the diagnostic accuracy of the sets when used in repairing malfunctions found during extensive mobility and armament testing. They recorded the success of each application of the sets and the time required to diagnose the fault. Development test III did not address the inherent accuracy of the sets over all possible faults, nor did it seek to explore

test set capabilities beyond the immediate needs of the ongoing maintenance task.

The challenge was to describe the impact of test set shortfalls—if such were found—in terms of the two measures discussed above. Test sets contribute

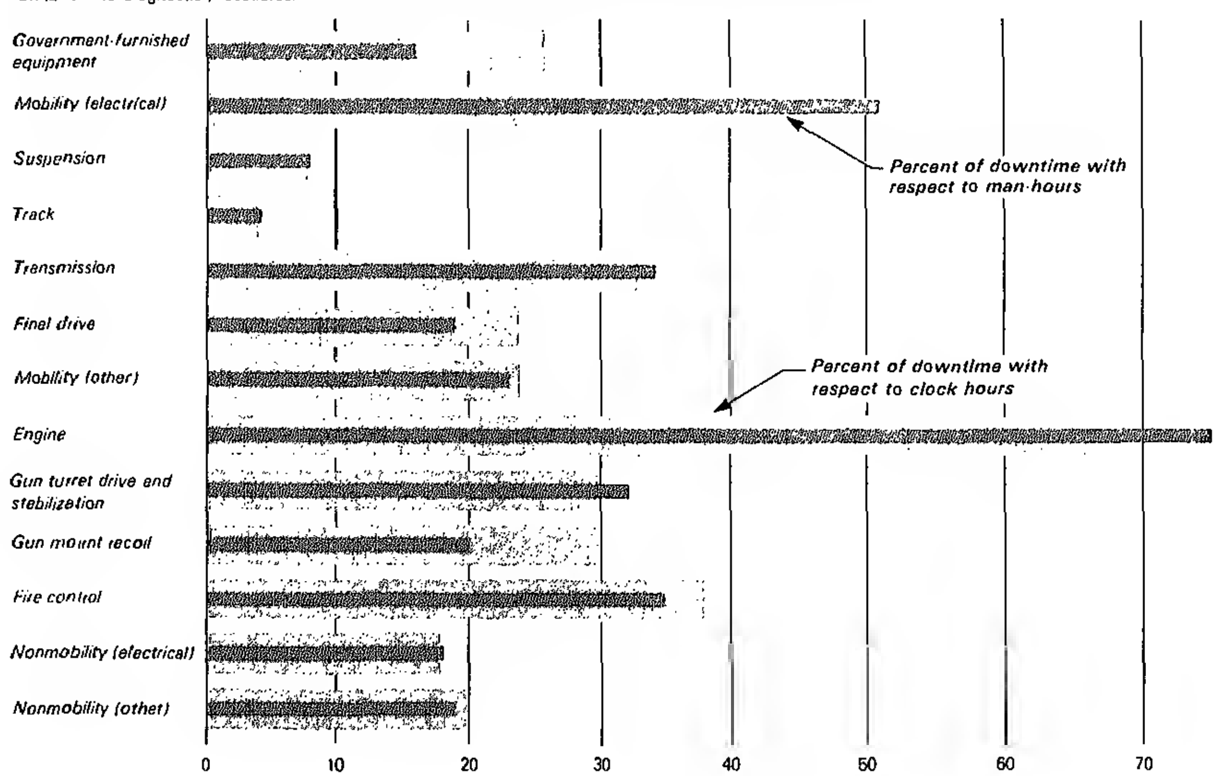
time. Expressed as an equation, the operational availability of the tank equals total operating and standby time divided by the sum of operating time, standby time, total corrective maintenance downtime, total preventive maintenance downtime, and total administrative and logistic downtime.

In wartime, standby and preventive maintenance downtimes become small in relation to operating time; consequently, total corrective maintenance time becomes a significant determinant of availability. Given that diagnostic downtime contributes substantially to total corrective maintenance downtime, the accuracy of the M1 test sets directly affects operational availability.

The relationship between test sets and operating and support costs was less well-defined. Inaccurate test sets can certainly result in increased man-hours

Figure 1. M1 tank downtime attributable to diagnostic procedures

Analysts studying malfunctions on the M1 tank found that the greatest maintenance burden involved diagnostic procedures, which accounted for more than 40 percent of the total downtime. This graph depicts the percent of total corrective maintenance downtime for major M1 subsystems that was attributed to diagnostic procedures.



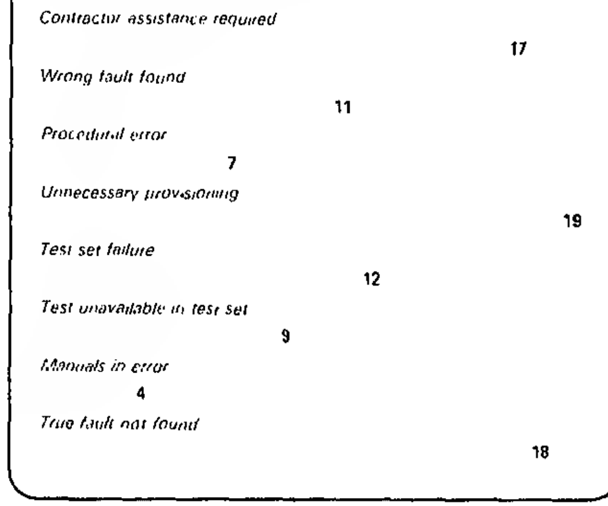
increased supply system costs as the inaccurate sets fill up supply pipelines with returned parts. Under ideal conditions, researchers could have determined the quantitative effect on operating and support costs by working from the baseline cost estimate for the M1 tank to investigate the increase in corrective maintenance manpower requirements indicated by test results. However, the reality of personnel limitations and tight schedules restricted analysis for the M1 to evaluation of qualitative linkages only.

Results of the test showed that diagnostics and test sets were not performing well. The greatest maintenance burdens were in the engine drive systems, for which average repair times exceeded two clock hours and three man-hours. Analysis of the malfunctions revealed no specific vehicle design problems that could explain these maintenance times, but did indicate a potentially serious problem with diagnostic procedures. In fact, diagnostic time consumed more than 40 percent of total downtime, and analysts in general found problems with diagnosing failures in both the power train and the vehicle's electrical systems. Figure 1 shows the proportion of total corrective maintenance clock hours and man-hours attributable to diagnostic time for major subsystems.

Researchers categorized each incident involving a separate and identifiable application of the test set as either satisfactory or unsatisfactory. Test set performance was satisfactory if technicians, following prescribed procedures, were able to successfully complete the maintenance event in which the test set was used. If they were not, and if the failure was related to use of the test set, the set's performance was unsatisfactory. In 37 of the 62 test set applications, performance was in fact not satisfactory. Figure 2 lists the problems encountered in order of frequency. (Some incidents involved multiple problems; thus the total number of incidents exceeds 37.)

Some repairs or malfunctions can necessitate the successful completion of multiple subtasks in order to provide the maintenance required in a particular incident. Therefore researchers did a separate analysis to judge each maintenance incident as an entity, regardless of the number of individual subtasks involved. Of the 49 incidents analyzed, only

The M1 test set performed unsatisfactorily in 37 of 62 sample maintenance applications (because some incidents involved more than one problem, the total exceeds 37)



16 would have been successfully completed in the field.

Investigation of the test set shortfalls indicated that the Army could anticipate significantly increased demands for provisioning and manpower, as well as substantial administrative and logistic downtime in the field, while waiting for functioning test sets, seeking contractor assistance, or pursuing faulty troubleshooting. The numbers spoke eloquently—diagnoses were taking 32 percent of all repair time. In a combat situation, where standby time and preventive maintenance time decrease drastically, operational availability becomes very sensitive to changes in diagnostic time.

Moreover, an increase in provisioning actions due to erroneous diagnosis degrades operational availability. Each faulty diagnosis can cause an unnecessary provisioning action and thus result in substantial loss of time. As is clear from the equation presented earlier, additional administrative and logistic downtime further reduces operational availability.

The impact of these problems on operating and support costs is readily apparent. Incorrectly replacing a good part results in provisioning at an unnecessarily higher rate for that part. Tasks which cannot be completed without contractor assistance imply expensive contractor support in the field, but contractor support may not always be available in

illustrates two key points about the role of logistics in weapon system acquisition:

- Careful planning for supportability test and evaluation *can* illuminate critical logistic support shortfalls.
- Comprehensive evaluation *can* help capture the assets necessary to correct the shortfalls identified.

The Developmental Supportability Test and Evaluation Guide outlines procedures for doing both.

International considerations

wartime. Also, increases in diagnostic time consume maintenance man-hours that are directly traceable to requirements for soldiers in tank maintenance organizations.

The Army Materiel Systems Analysis Activity presented the detailed evaluation of the test set problem to decision-makers at the production decision milestone. Based on results of the in-depth analysis, the Army created a new program solely to determine the corrections needed in this critical area. The service committed the necessary assets, including test items (two complete M1s), personnel, and dollars, to a two-shift-per-day effort to resolve the problem, and the accuracy of the sets has improved. Interim results from the phase II M1 tank durability test show an 80 percent test set success rate.

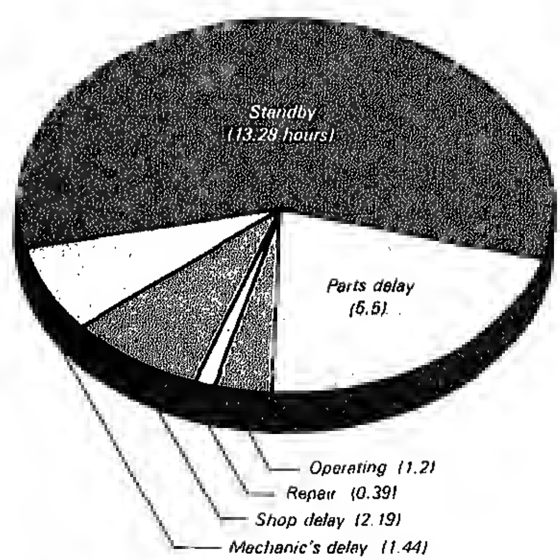
Using data obtained on the M1 during its first year of fielding in Europe, Army personnel have also computed the variables for the operational availability equation discussed above. An extensive, service-funded, sample data collection program yielded sufficient detail to show how the M1's time was spent in the field. Figure 3 gives the average time the M1 was in each status.

Data indicated that by eliminating faulty provisioning the Army could improve operational availability for the M1 in Germany by five to ten percent. The magnitude of the numbers in this example is not important; what decision-makers do need to know is that even a small improvement in operational availability is significant and achievable. By quantifying the usefulness of improving an item such as test sets, an evaluator can advise decision-makers whether the problem is solv-

The more international in scope a system is, the more urgent the need to plan and evaluate support for it. In any logistics train involving intercontinental distances, order and ship times become critical because the availability of the end item depends on the availability of spare and repair parts. Inventory situated abroad carries with it associated management, storage, and investment costs which planners must factor into the operating and support costs of the system.

Figure 3. A day in the life of the M1

When the Army gathered and analyzed sample data from the M1's first year of fielding in Europe, it discovered that only a small percentage of the vehicle's average daily downtime was actually attributable to repair work.



pose problems unique to international logistics. For example, DoD has had to return an aluminum tactical bridge purchased from a European firm so that the European manufacturer could weld cracks in the structure—the U.S. had not purchased the fixtures required to align the sections for welding. Moreover, the engines and other complex parts of trucks and boats purchased from foreign manufacturers are often proprietary designs; therefore, the United States may experience difficulty in procuring spare parts should the original suppliers decide to discontinue producing the engines in the configuration purchased.

In addition, the adequacy of technical data and equipment publications is a feature which varies widely among international acquisition programs. Some publications are remarkably complete and comprehensive, while others appear to be only rough translations and require substantial effort to convert to manuals that meet Army standards. All these considerations in international programs are subject areas for logistic supportability test and evaluation.

The international effort known as standardization and interoperability, elevated to the status of an "element" in the latest version of the Army's integrated logistic support regulation (AR 700-127), underscores the need for such testing and analysis. The objective of this program is to insure that western forces can operate together if the need arises. Joint operations of international forces help officials identify shortfalls in the logistic support systems for equipment that could reasonably be called upon to operate together on the battlefield; and U.S. acquisition programs are beginning to structure developmental tests and evaluations that include investigation of standardization and interoperability provisions in logistic support areas.

Recently, for example, program personnel identified inadequate design of a NATO standard cable connector installed on a U.S. ammunition supply vehicle under test. If not redesigned, the U.S. vehicle would have been unable to accept a jump start from an allied vehicle on the battlefield; as a result, a vital piece of U.S. equipment might have been rendered useless with only a dead battery. Tests specifically designed to address standardization and interoperability help analysts find and correct supported together, design of test and evaluation methods for standardization and interoperability needs to continue.

The Army's recently published guide already offers a structured method for designing and conducting tests and evaluation of logistic support systems, and experience with the M1 tank has shown the value of this approach. The method developed gives incentives to investigate high-opportunity areas. It enables evaluators to link shortfalls in logistic support to the real-world indicators of operational availability and operating and support costs, and program personnel thereby gain leverage in convincing decision-makers to assign assets to correct the shortfalls. The evaluator can demonstrate what logisticians have felt for years—that acquiring adequate logistic resources to support the performing end item is money well spent.

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Applying linear programming to logistics planning

By RICHARD A. REID
and
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To allocate limited resources among competing requirements, logistics managers are increasingly turning to the computer for help.

Logistics managers frequently have to allocate scarce resources among competing demands in order to either maximize level of service or minimize total cost. Challenges of this nature, often in the form of distribution problems, are particularly common in the supply and transportation functions. The distribution problem requires, for example, that a logistician formulate the minimum-cost shipping schedule for a commodity stored in limited quantities at various supply sites and needed by users at other locations.

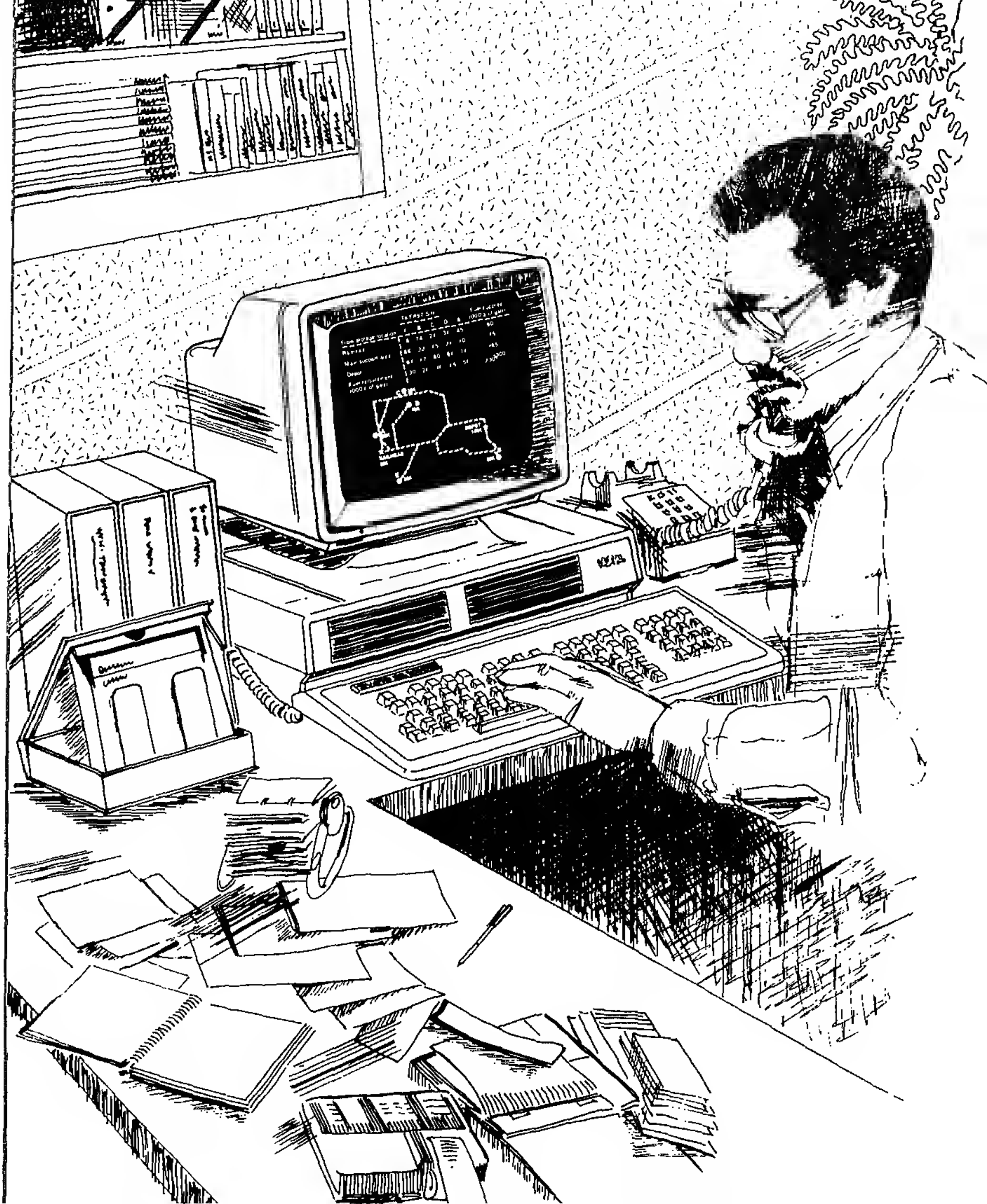
Distribution problems are typical of managerial problems that can be solved through linear programming, an analytical technique that identifies an optimal solution for problems having a variety of restrictive factors and feasible solutions. This generalized, computer-based modeling technique enables the logistician to identify a shipping schedule that will satisfy all user-destination requirements while incurring lowest possible distribution costs.

Linear programming, of course, is not the only approach available for solving such problems. Many logistics managers are already familiar with several other methodologies subsumed under the rubric of the transportation model. Among them are the Northwest Corner Rule and Vogel's Approximation Method, which can provide initial feasible solutions, and the Stepping Stone Method and the Modified Distribution procedure, which can aid in evaluating alternative solutions and in identifying changes necessary to achieve optimality. Underlying these methodologies are special mathematical structures that produce solution efficiencies not generally available in linear programming codes.

However, today's logistician is more likely to have ready access to a canned linear programming package, one compatible with widely available desk-top microcomputers, than to a preprogrammed computer code that utilizes these other methodologies. Moreover, a good linear programming computer code produces a post-optimality data set, a feature that enables managers to quickly analyze the effect that changes in initial conditions will have on existing plans and to develop contingency plans accordingly.

The following hypothetical fuel distribution problem illustrates the concepts and procedures involved in transforming problem scenarios into appropriate input structures for linear programming processing. It posits a logistics manager who needs to determine the least costly plan for distributing fuel from three storage locations to meet the requirements of six user destinations. Figure 1 (p. 28) shows the mileage relationships between supply sources and destination sites, the quantities of fuel available from each supply source, and the quantities required by the destination sites.

Formulating a linear programming problem is a three-step process. First, the decision variables, those factors over which the manager has control, must be identified. Next, the objective function, a mathematical statement that represents managerial interests such as profit, revenue, share of the market, or costs, must be stated as a mathematical expression to be minimized or maximized. Finally, the constraint set, or limits on the



mathematically specified in the form of equalities or inequalities.

Characteristic of all distribution problems are multiple sources or supply locations having limited quantities of a commodity that is required in specific quantities at various destinations. A number of workable shipment schedules may exist but management naturally seeks to identify the particular shipment schedule that minimizes transportation costs. Such costs are linear, that is, directly proportional to distance traveled.

Adequate definition of a problem is a necessary prelude to solving it. Particulars of the fuel distribution problem are as follows:

S = the supply source.

m = the number of supply sources (three), designated S_1 (railhead), S_2 (depot), and S_3 (main support area).

D = the destination.

n = the number of destinations (six), designated D_1 through D_6.

ij = the supply source-destination pairing.

C = the unit shipping cost in gallon miles.

C_{ij} = the cost of shipping one unit of product from a given supply source to a given destination.

X_{ij} = the quantity of product that can be shipped from a given supply source to a given destination.

Thus, C_{26} represents the cost of shipping one unit of fuel from depot S_2 to destination D_6. The number of possible routes is 18 ($m \times n = 3 \times 6$), and each has an associated cost which is assumed to be directly proportional to the mileage traveled. In other words, assuming that transportation costs per mile on each route are equal, the unit cost of fuel shipped from S_1 to D_3 is 74, or $C_{13} = 74$, the number of miles between the two sites (see Figure 1). When that assumption does not hold, such as when one roadway is mountainous, the mileage figure has to be adjusted accordingly.

As is the case in cost calculations, the ij subscript in quantity calculations designates the source-destination pairings. If the optimal solution includes $X_{35} = 45$, for example, then total distribution costs are minimized if 45 thousand gallons are shipped from S_3 to D_5. The computerized linear programming code uses the same subscript notation.

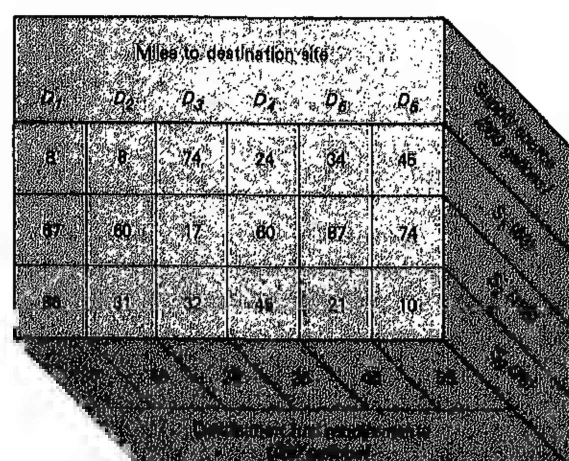
Specification of the 18 decision variables [X_{11} through X_{36}] as the number of gallons (in thousands) to be shipped from a given supply source to a given destination completes the first step in formulating the linear programming problem. When decision variable values, such as thousands of gallons of fuel, are multiplied by source-to-destination mileage, the product equals the total cost in gallon-miles for an entire shipment schedule; therefore, one can calculate the total number of gallon-miles by evaluating the following objective function: $8X_{11} + 8X_{12} + \ldots + 74X_{36}$.

The objective function in this instance is subject to a set of supply ($m = 3$) and demand ($n = 6$) constraints. A supply constraint represents an on-hand quantity of fuel available for shipment at a given supply source. It indicates that the quantity of fuel that can be shipped from that source is equal to or less than the amount on-hand. For example, the canned computer linear programming code views the relationship between the railhead (S_1), which has 60 thousand gallons of fuel on-hand, and each of the six destinations as: $X_{11} + X_{12} + X_{13} + X_{14} + X_{15} + X_{16} \leq 60$. In other words, the quantity of fuel shipped from the railhead to destinations D_1 through D_6 must be less than or equal to the 60 thousand gallons that are available. The remaining two supply constraints, for the depot (S_2) and the main support area (S_3), can be stated, respectively, as: $X_{21} + X_{22} + X_{23} + X_{24} + X_{25} + X_{26} \leq 75$ and $X_{31} + X_{32} + X_{33} + X_{34} + X_{35} + X_{36} \leq 165$.

Demand constraints represent the amount of fuel required at each destination. The total quantity shipped to a destination must equal its requirement. For the fuel distribution problem hypothesized, the relationship of fuel requirements at each of the six destinations relative to the three supply sources is as follows:

D_1: $X_{11} + X_{21} + X_{31} = 30$
D_2: $X_{12} + X_{22} + X_{32} = 40$
D_3: $X_{13} + X_{23} + X_{33} = 25$

Figure 1. The data table for a hypothetical fuel distribution problem



D_6: $X_{16} + X_{26} + X_{36} = 55$

To ensure that only feasible sets of variable values will be considered, the model also imposes non-negative constraints. That is, it requires that the solution values for each of the 18 decision variables be equal to or greater than zero. In the sample problem, for instance, $X_{ij} \geq 0$ for $i = 1, 2, 3$ and $j = 1, 2, 3, 4, 5, 6.$

After using a computer-based linear programming code to identify an optimal solution, the logistics manager will want to analyze other important information in the solution printout. The post-optimal data set helps a manager determine the value of the resources utilized in meeting the objective, the range over which these resource values are valid, and the impact that change in the objective function coefficients will have on the validity of the specified optimal solution. Although the information in the tables that follow has been extracted from a printout generated by the Hewlett Packard canned linear programming package, any good computer code will offer the same data, although the format may vary slightly from that shown here.

The shipping schedule in Figure 2 is the optimal solution to the sample fuel distribution problem. It indicates that total gallon-miles or costs are minimized at 6,700 thousand. Interestingly, shipping costs can be minimized by distributing fuel from two or more storage locations to a single destination. For example, destination 6 is to receive 25 thousand gallons from the depot

As Figure 2 indicates, the optimal solution includes a value of 70 thousand for a decision variable labeled Slack 3. The meaning of this value is that all destination requirements will be met and total gallon-miles or costs will be minimized if site 2, the depot, retains 70 thousand of its original 165 thousand gallons. Shipping routes not included in the optimal solution will not be used.

Shadow prices for the hypothetical example are shown in Figure 3. In effect, they are opportunity costs; shadow prices represent the value of one additional unit (thousand gallons) available at each storage location or required by each destination. Specifically, the objective function value or total fuel transportation cost of 6,700 thousand gallon-miles will increase or decrease by the shadow or imputed price (in thousands of gallon-miles) as the supply availability at any storage location increases or decreases correspondingly.

The objective function value will also increase or decrease if the fuel requirements at any destination increase or decrease. For instance, a 1,000-gallon increase in the fuel supply at the railhead would reduce by 52 thousand (the difference between 6,700 thousand and 6,648 thousand) the minimum number of gallon-miles required to fulfill all destination requirements from available storage location supplies. Therefore, if the railhead can supply an additional unit of fuel at a cost less than 52 thousand gallon-miles, the logistics manager has an opportunity to reduce total shipping costs.

Figure 3. The opportunity costs for the hypothetical fuel distribution problem

Constraint symbol	Fuel available or required	Shadow price (opportunity cost)
Railhead	60	52
Main Support Area	75	64
Depot	165	0
D_1	30	-60
D_2	40	-70
D_3	25	-17
D_4	35	-60
D_5	45	-65
D_6	55	-74

Figure 2. The optimal solution to the sample fuel distribution problem*

Decision variable	Supply source	Destination site	Fuel shipped (000 gallons)
X_{11}	Railhead	D_1	30
X_{12}	Railhead	D_2	30
X_{35}	Main Support Area	D_5	45
X_{36}	Main Support Area	D_6	30
X_{22}	Depot	D_2	10
X_{23}	Depot	D_3	25
X_{24}	Depot	D_4	35
X_{26}	Depot	D_6	25
SLACK 3	Depot	Nowhere	70

*OBJECTIVE FUNCTION VALUE EQUALS 6700 (IN 000 GALLON-MILES)

shipment gallon-miles—is possible.

The right-hand side value of each constraint inequality represents either the amount of fuel available at a storage location or the amount required at each destination. Figure 4 lists those values and shows the range over which they can vary and still produce, on a proportional basis, changes in transportation cost. For example, the fuel supply available at the railhead could decrease by 30 thousand gallons, resulting in a corresponding increase in the objective function value (cost) of 1,560 [30 × 52] thousand gallon-miles. Conversely, an increase of 10 thousand gallons at that supply source would result in a cost decrease of 520 [10 × 52] thousand gallon-miles. However, this kind of analysis is valid when only one right-hand side value is changed at a time.

Figure 5 shows the range over which an objective function coefficient can vary while the original linear programming solution remains optimal. For instance, the mileage between the railhead and destination 1 could increase by as much as 7 miles or decrease to zero, and the optimal fuel shipment schedule shown in Figure 2 would still yield the lowest cost or fewest gallon-miles. Naturally, any change in mileage values for those routes being used in the optimal schedule will result in a corresponding change in the objective function value. But again, the original solution might remain the optimal one, as it would, for example, if the 8-mile distance between the railhead and destination 1 were to change to

value or transportation cost would increase by 180 thousand gallon-miles [(14 − 8) × 30] to 6,880 gallon-miles, but would not affect the optintal shipment schedule. As in the case of right-hand constraint values, such analysis is not valid when two or more objective coefficients change at the same time.

In short, analysis of lincar programming post-optimality data can provide an abundance of useful decision-making information. It enables logisticians to better address three key areas of managerial concern. First, managers can assess the need for more accurate input data. For example, the 60-mile distance between the depot and destination 2 may only represent the average of the two available estimates of 50 and 70 miles. But if either of these two latter figures is indeed correct, then

Figure 4. The range over which the amount of fuel available or required can vary and still produce proportional changes in transportation costs

Constraint symbol	Fuel available or required	Range: lower limit	Range: upper limit
Railhead	60	30	70
Main Support Area	75	45	100
Depot	165	95	Unbounded
D_1	30	20	60
D_2	40	30	110
D_3	25	0	95
D_4	35	0	105
D_5	45	20	75
D_6	65	30	125

Figure 5. The range over which the objective function coefficient (roadway distance) can vary while the original linear programming solution remains optimal

Decision variable	Supply source	Destination site	Distance: source to destination	Range: lower limit	Range: upper limit
X_{11}	Railhead	D_1	8	*	15
X_{12}	Railhead	D_2	8	1	9
X_{35}	Main Support Area	D_5	21	*	22
X_{36}	Main Support Area	D_6	10	9	48
X_{22}	Depot	D_2	60	59	67
X_{23}	Depot	D_3	17	0	96
X_{24}	Depot	D_4	60	0	76
X_{26}	Depot	D_6	74	39	76
BASIS					
X_{13}	Railhead	D_3	74	*	*
X_{14}	Railhead	D_4	24	8	*
X_{15}	Railhead	D_5	34	33	*
X_{16}	Railhead	D_6	46	22	*
X_{31}	Main Support Area	D_1	86	*	*
X_{32}	Main Support Area	D_2	31	*	*
X_{33}	Main Support Area	D_3	32	*	*
X_{34}	Main Support Area	D_4	46	*	*
X_{21}	Depot	D_1	67	60	*
X_{25}	Depot	D_5	87	86	*
NONBASIS					

*Unbounded

Post-optimality analysis facilitates rapid, intelligent, and effective planning. When applied to the design and evaluation of optimal shipment schedules, it allows a manager to concurrently consider both tactical and logistical factors.

the shipment schedule in Figure 2 is not the optimal one, for total costs or gallon-miles are minimized only if the actual roadway distance between the two locations in question is between 59 and 67 miles (see Figure 5). In other words, the optimal shipment schedule is sensitive to this input value of 60, and it behooves management to determine the distance between the two points as accurately as possible to ensure that the lowest cost schedule is identified.

Post-optimality analysis also aids contingency planning. An effective manager must be prepared to identify alternative optimal shipment schedules should changes occur in the initial scenario. To construct alternate plans, the logistician can draw upon the insights gained from analyzing post-optimality data. To illustrate, consider the impact on the existing optimal shipping schedule if a 50-thousand-gallon storage tank is destroyed at the depot. Given such a situation, post-optimality analysis eliminates the need to revise the input data and rerun the linear program in order to obtain a new shipment schedule. The logistician already knows that fuel stored at the depot has an imputed transportation cost or shadow price of zero; because this cost is valid as long as the amount of fuel stored there exceeds the lower limit of 95 thousand gallons, the total fuel shipment cost will remain minimal under the existing transportation schedule.

A more comprehensive approach to decision-making is the third principal benefit. In the past, when unexpected changes in input values required that logisticians develop alternative shipment schedules, they tended to focus on tactical considerations such as whether a roadway had adequate drainage or few bottlenecks. Post-optimality analysis facilitates rapid, intelligent, and effective planning; thus, when applied to the design and evaluation of optimal shipment schedules, it allows a manager to concurrently consider both tactical and logistical factors.

Although this paper has focused on the standard distribution problem, other common types of logistics problems are amenable to solution by linear programming as well; among them are facility location, vendor selection, aggregate planning, and cargo composition problems. Fortunately, the wide availability of desk-top computers has increased the logistician's opportunities to use canned modeling packages like linear programming for such applications. Skills in formulating problems and analyzing computer-generated results have in fact become essential for effective logistics management.

Both novice and experienced logistics managers need such skills. Appreciating the sensitivity of a decision to changes in variable values can be as important as the decision itself. A manager, aware that a solution is not critically sensitive to certain inaccuracies in input data, has some assurance that the solution will remain optimal even if minor changes occur prior to implementation. But if a decision is sensitive to even slight changes in variable values, those values must be as accurate as possible. Managers need to be able to identify such situations as well. DMJ

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An aid for evaluators of system design alternatives

By DENNIS M. BUEDE
and
ROBERT W. CHOISSER

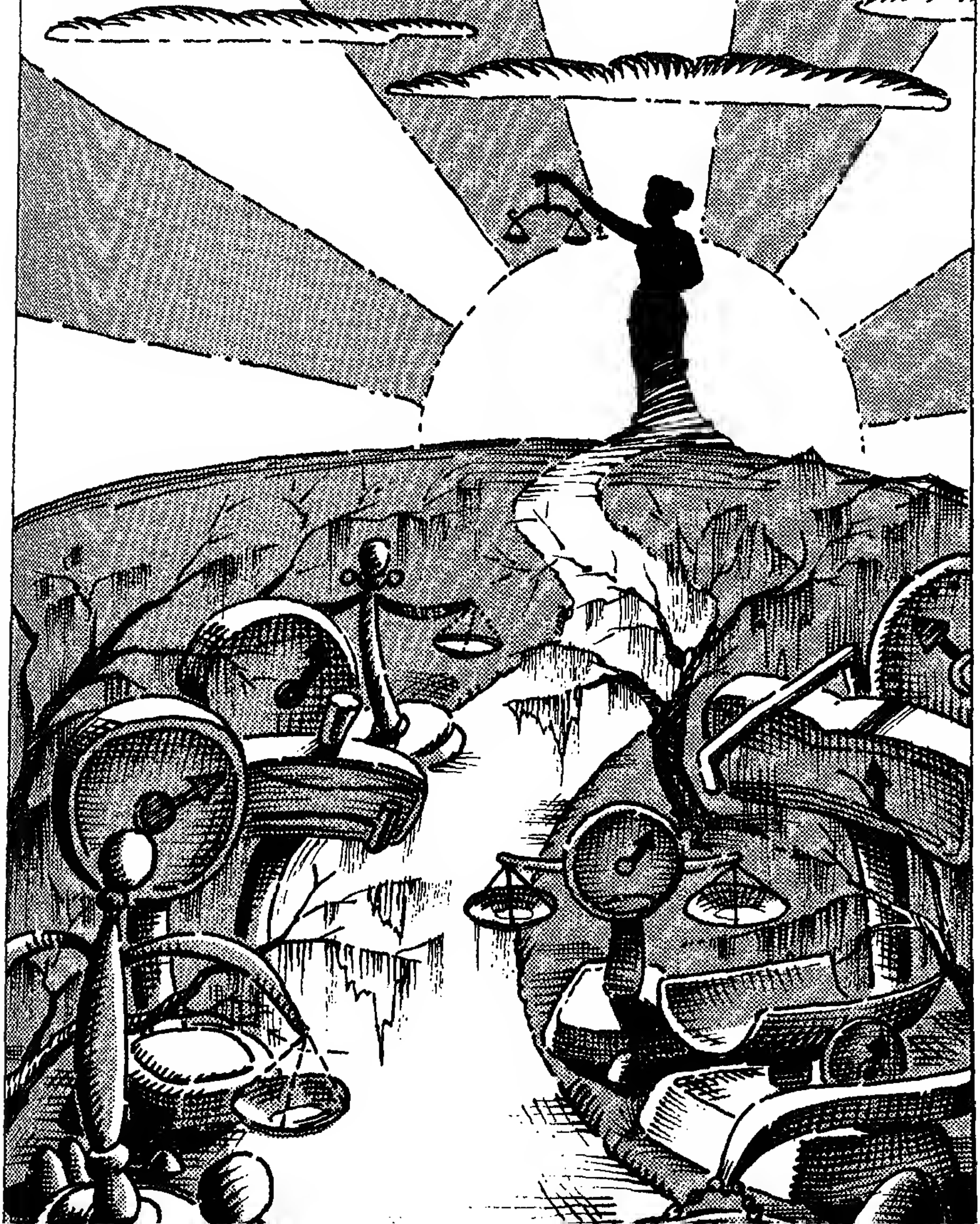
Evaluating multiple performance factors among system design alternatives requires a coherent methodological framework. Multidimensional value theory meets that need.

Designing a system architecture is often the initial stage in any system development and can be the most critical one. During the architectural design phase, analysts examine many important configurational alternatives and eventually discard all but one. Each potential configuration has unique strengths and weaknesses, and the decision process involved must deal with all the diverse facets of system effectiveness and cost. Decision analysis, in particular multidimensional value theory, offers an approach that is not only adequate to the complexities of the process but one that yields a number of other advantages as well.

Decision analysis gives system designers a structured, logical, analytical methodology for evaluating alternative architectural configurations. Multidimensional value theory, developed as part of a program sponsored by the Defense Advanced Research Projects Agency, provides a basis for subdividing effectiveness and cost, which comprise the bottom line, into their component parts. The system design team can subdivide these component parts as finely as necessary to allow individual team members to focus their expertise, in turn, on specific issues. Synthesis of the results yields an end product that decision-makers can use with confidence.

Among the benefits of this approach are increased objectivity, less risk of overlooking significant factors, and perhaps most important, the ability to reconstruct the selection process rather than invoking intuition in explaining the configuration selected. A distinct advantage of decision analysis over cost-effectiveness, the traditional methodology, is that the former does not require absolute, all-encompassing judgments concerning the relative importance of the various effectiveness factors; assignment of weighted values is much less subjective. Decision analysis provides a pragmatic, problem-specific interpretation for such judgments, as the example that follows will demonstrate. Because the results are quantitative, evaluators can conduct sensitivity and "what if" analyses at an early stage in system design to determine the robustness of the results and to identify key factors that can affect the results.

The application of multidimensional value theory discussed below highlights key features of the methodology. The project involved design of the Worldwide Digital System Architecture, a comprehensive architecture that will guide development of all future Defense Department common-user telecommunications systems. Over a five-month period, a decision analysis team evaluated alternative architectures in three, successively more detailed phases. They considered a wide range of



analyses, allowed the study team to eliminate several architectural concepts from further consideration during the first and second phases. The value tree exercise also focused attention on technical areas that should be exploited in creating more detailed architectural alternatives for the second and third phases of the evaluation.

The objective of the evaluation was to recommend a goal architecture for 1995, selected from a set of explicitly defined alternatives, that would provide direction and focus for the evolutionary development of DoD telecommunications systems. The alternative recommended had to be sufficiently broad in scope to accommodate tactical, allied, and Defense Communications Systems users; on-base as well as long-haul commutications; and the gamut of user services, among them, clear voice, secure voice, data, and hard copy.

Before developing a value tree, the evaluation team formulated detailed and explicit statements of user requirements. From these statements and a description of the present, or baseline, system, the team derived a set of needed improvements to the system. The system deficiencies identified formed the basis for postulating the alternative architectures described below. The team then applied multidimensional value theory in comparing these alternatives to determine which was best suited to serve as the good architecture for the Worldwide Digital System.

Figure 1. Evaluators compared eight progressively advanced designs to determine which was best suited to serve as the Worldwide Digital System Architecture.

FAMILY 1	Hierarchical emphasis on backbone Independent voice and data networks Upgrades to baseline in accord with commercial trends Common-channel signaling in backbone Gateways at backbone
1A: Minimum cost	Reliance on commercial resources Eliminate some current facilities
1B: Enhanced hardening	Facilities hardening Switch relocations Subsidized commercial facilities for hardening and restoral
1C: Flexible access nodes	Multirate switch capability Ability to reroute and reallocate traffic
FAMILY 2	Extend backbone functions to access nodes Mutually supportive voice and data networks
2A: Fixed facility interfaces	Common-channel signaling to access level Access tandeming Multirate switches Enhanced control for restoration Data and voice backbone interconnects Improved secure voice key distribution New 16-kilobit-per-second voice algorithms
2B: Enhanced tactical interoperability	Improved gateways and traffic management
2C: Enhanced secure data	End-to-end encryption for data
FAMILY 3	Fully distributed, integrated voice and data networks Modularized switching Front-end encryption for all traffic Common signal structure (standards) Distributed uniform connectivity Common-channel signaling to local level Enhanced wideband transmission Enhanced system control Fully interoperable
3A: Fixed plant	Heavy reliance on commercial facilities Wideband links - mostly terrestrial Built-in contingency capability
3B: DoD-furnished satellites	Wideband links - mostly satellites Earth terminals Highly mobile assets Flexible reconstitution

Figure 1 lists principal features of the eight alternatives compared, categorizing them into three families of increasingly advanced design. With a basis in existing common carrier trends, alternatives in the first category achieved economics of scale through larger tandem switches and use of expanded transmission routes such as the East Coast optical fiber route and multibeam satellites. The second group exploited increased processing at the access nodes, use of additional paths through a variety of networks, and use of access switches to enhance integration of functions. The third family carried current telecommunications trends to their

signals.

Central to multidimensional value theory methodology is the valuc tree, a hierarchical structure of evaluation criteria that differentiates between the alternatives being considered. The highest-level criteria typically reflect the decision-maker's major concerns or goals, such as maximizing effectiveness or minimizing cost.

For evaluation of the Worldwide Digital System Architecture, cffectiveness and implementation were the two highest-level critcria (see Figure 2). The decision analysis team subdivided cach of these in turn: effectivencss into performance, security, survivability, and responsiveness; implementation into cost, risk, and easc of transition. However, these factors were still too inclusive of multiple dimensions to permit an analytical evaluation with well-defined value scales. Consequently, evaluators subdivided each one until they reached a level of critcria they could adequately quantify in terms of the alternative architectures being considered. This initial evaluation phasc required several iterations of value trees bcfore the analysts and evaluators were confident that the important factors were properly addressed.

The next step is scoring each of the lowest-level

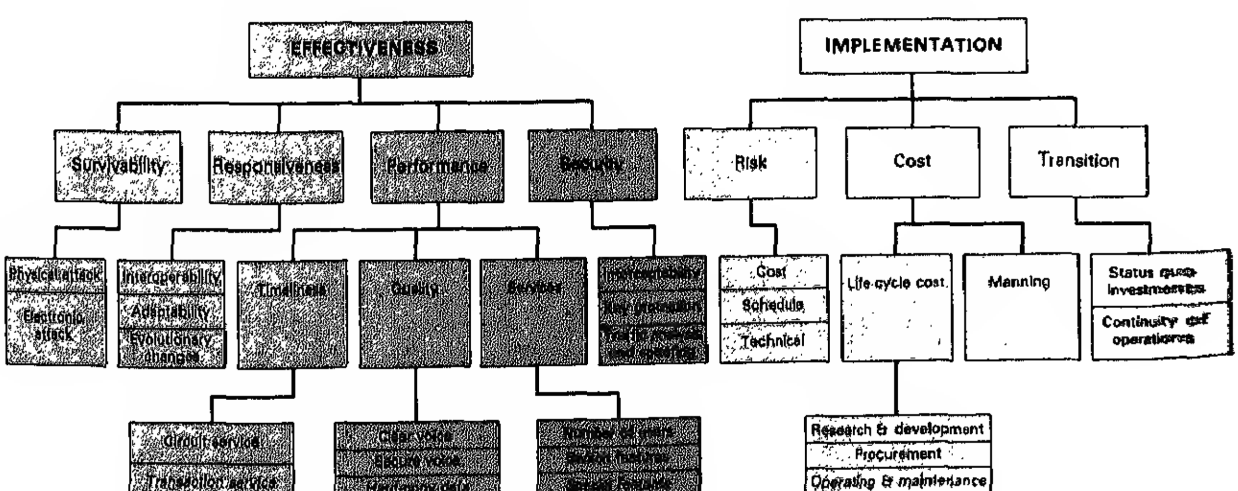
lute measures of effectiveness against which any alternatives can be compared. However, because alternatives for the Worldwide Digital System Architecture were already well-defined, cvaluators followed a three-step, relative scoring procedure which bypassed the definition of value functions:

- They first determined which alternative provided the greatest cffectiveness (or required the least implementation) on a given criterion and set its score at 100.
- Next, they identified the alternative that provided the least effectiveness (or required the most implementation) on the same criterion and gave it a score of 0.
- Finally, the team scored the remaining alternatives for the criterion on a cardinal value scale between 0 and 100.

A cardinal value scale preservcs measures of equal differences, just as the centigrade temperature scale does, for example, but attaches no analytical meaning to the end points. The numbers 0 and 1,000 or 100 and 200 could havc served just as well as end points without changing the results. If values range from 0 to 100, a score of 50 indicates that the satisfaction level or value for an alternative is midway between the best and worst.

In assigning a score to each alternative, eval-

Figure 2. The two highest-level criteria, effectiveness and implementation, were subdivided three times before evaluators were confident that the important dimensions of each were properly defined



important judgments; therefore value scores do not necessarily bear a linear relationship to the technical parameters defining the criterion. The first judgment was technical—how does the alternative being considered differ in delivering clear voice quality, for example, from the best and worst alternatives? The second judgment reflected the value or degree of satisfaction that these technical differences held for architecture users; it is a key input for system users.

This scoring procedure requires that analysts check to determine whether evaluators' responses are sensitive to different scenarios in which a system might be used. For evaluation of the Worldwide Digital System Architecture, conditions postulated ranged from peacetime to mobilization to wartime and included national emergencies as well. However, the consensus was that differences among these conditions would not affect the scoring judgments.

Figure 4. First-level effectiveness versus implementation scores were plotted for the nine options shown in Figure 3

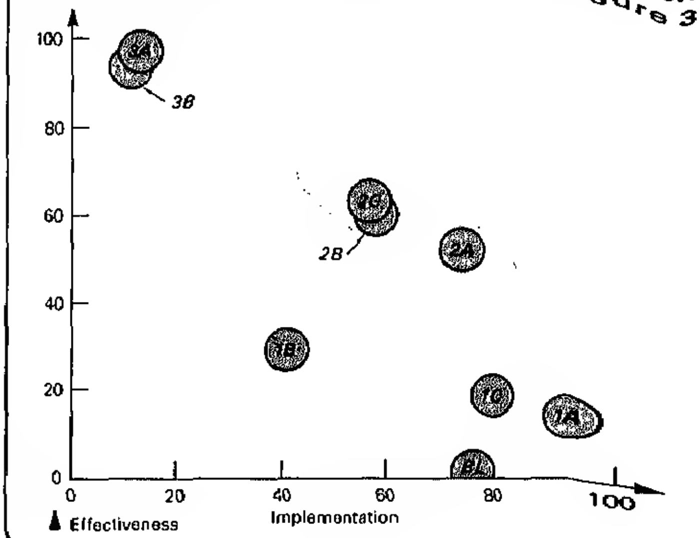


Figure 3. First- and second-level criteria were assigned values for both the baseline system and the eight alternative architectures

WWDSA VALUE TREE

	WT	BL	1A	1B	1C	2A	2B	2C	3A	3B
Effectiveness	.5	1	14	29	19	52	59	62	97	93
Implementation	.5	77	94	40	80	74	58	56	13	16
Total		39	54	34	50	63	59	59	55	54

EFFECTIVENESS

	WT	BL	1A	1B	1C	2A	2B	2C	3A	3B
Performance	.2	5	36	36	40	60	56	60	95	96
Security	.2	0	5	29	11	18	33	44	95	95
Survivability	.35	0	0	30	10	60	60	60	100	86
Responsiveness	.25	0	23	20	23	60	82	82	96	100
Total		1	14	29	19	52	59	62	97	93

IMPLEMENTATION

	WT	BL	1A	1B	1C	2A	2B	2C	3A	3B
Cost	.4	66	97	16	74	64	53	61	30	35
Risk	.25	66	80	19	78	86	67	64	5	3
Transition	.35	97	100	83	87	78	57	57	0	10
Total		77	94	40	80	74	58	56	13	16

After assessing values and assigning scores to all alternatives at each bottom-level criterion, analysts undertake the final step in the quantification portion of the analysis. It consists of aggregating bottom-level scores within a cluster such as security in order to derive valid value scores for that intermediate criterion. Analysis must develop aggregation rules for every cluster of criteria, from those at the lowest level in the value tree to that at the highest, which combines the effectiveness and implementation criteria discussed above.

The simplest principle for combining user values across incommensurable criteria is weighted averaging, a technique analogous to establishing exchange rules for different currencies. For subcriteria within each cluster of intermediate- and upper-level criteria, analysts assign weighted values, ranging from 0 to 100, based on input from the evaluators and decision-makers. These weighted values have to satisfy the properties of a ratio scale; in other words, ratios must be preserved and zero has an analytical meaning, that is, no value. Once determined, weighted values are normalized (multiplied by a constant) to total 1.0, so that analysts can calculate the weighted average.

Figure 3 tabulates initial evaluation results for

Figure 5. Evaluators conducted a sensitivity analysis for the effectiveness factor which pointed to alternatives 1A, 2A, and 3A as most effective

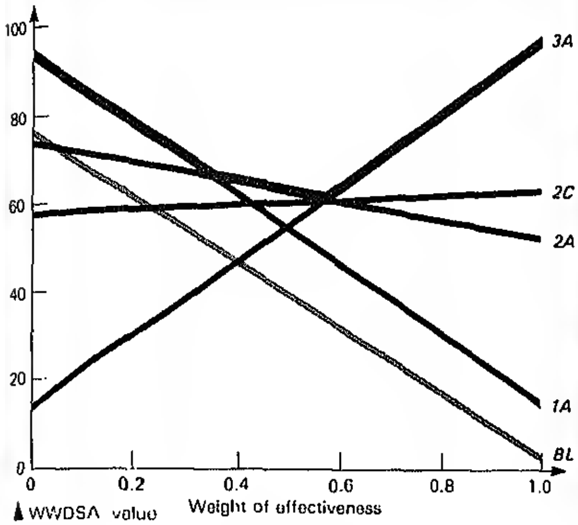
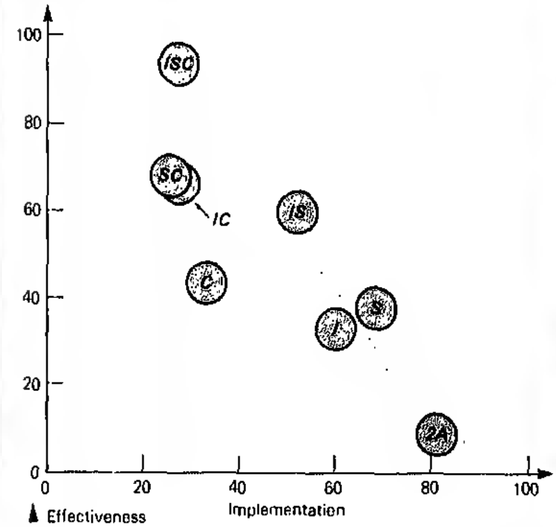


Figure 6. Using option 2A as the new baseline, evaluators defined and ranked seven, more finely tuned alternatives



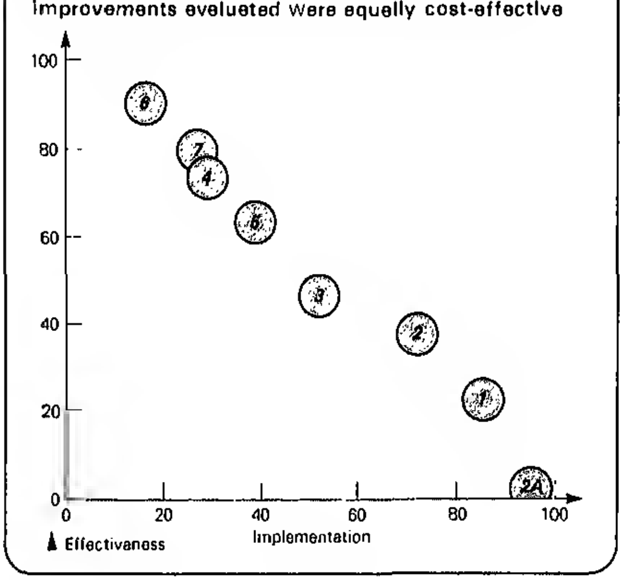
System Architecture value tree. It presents data for both the baseline, or current, system and the eight other alternatives outlined in Figure 1. For the same nine options, Figure 4 plots first- or top-level effectiveness versus implementation scores. A low implementation score indicates a costly, difficult-to-transition system, whereas a high score denotes an inexpensive, easy-to-transition system; only alternatives falling near the outer envelope are optimal candidates.

Because the top-level weights were difficult to establish, evaluators conducted a sensitivity analysis for the effectiveness factor. The results, displayed in Figure 5, pointed to alternatives 1A, 2A, and 3A as most effective, depending upon the relative weights assigned to effectiveness and implementation. Alternative 1A totally dominated the baseline system, thus indicating that the implementation of that option would be better than the status quo under any circumstances.

Given this justification for a change, decision-makers focused their attention on identifying the alternative that best satisfied effectiveness and implementation criteria. Two candidates, 2A and 2C, delivered solid performance at reasonable implementation costs throughout the range. Because family 1 alternatives were only marginal y family 3 due to the high cost and risk it would entail if implemented in 1995.

Based on results of the initial evaluation, analysts decided to identify additional options within family 2 and then conduct a second evaluation. Using option 2A as the baseline alternative for the family, the design team defined three incremental improvements in the areas of interoperability, communications security, and satellites. Labeled options I, C, and S, respectively, these three improvements, combined with one another, yielded four additional alternatives (IC, CS, IS, and ICS), bringing the total number to eight. (The current, or status quo, system was no longer an alternative at this point.)

Evaluated against the same effectiveness and implementation criteria discussed above, the eight alternatives ranked as shown in Figure 6. Option 2A was now the least costly, but also the least effective, alternative. Results indicated that, given additional resources, DoD should first acquire the satellite improvement, then the interoperability improvement, and finally the communications security improvement. Program officials therefore instructed the design team to use features of the 2A, S, IS, a d ICS ptions in developing even



Option 2A was again the baseline for this final evaluation, which considered seven additional options incorporating satellite capabilities, interoperability, communications security, and the multirate access switch. The third analysis showed these alternatives scattered almost evenly along a straight line on the effectiveness-implementation scale. The results thus indicated that the incremental improvements evaluated were equally cost-effective. Therefore the amount of transition resources, or dollars, available should drive the final decision. Such results are not uncommon when, as in this instance, an analysis has been iterated to fine levels of detail (see Figure 7).

From this series of multidimensional value analyses, option 7 emerged as the best candidate for the Worldwide Digital System's goal architecture, and the Joint Chiefs of Staff have approved key features of this architecture for planning purposes. The analysts and evaluators for the project completed the scoring of the alternatives, which typically takes several months, in only three two-day meetings and at half the normal cost. They were able to do so by taking advantage of unique interactive computer software and a specially designed conference room. The latter was equipped with a rear-projected, large-screen video monitor for displaying computer output to the group and

Structuring evaluation criteria for system design into a hierarchy, as was done for the Worldwide Digital System Architecture, provides valuable insight into the goals of the system. At the same time, it yields information useful in iteratively improving the design. The diverse factors that must be considered in initially conceptualizing a system design in fact require a structured, systematic approach.

The analytic process involved in applying multidimensional value theory also helps managers efficiently use the talent available to them. It allows them to focus specialized technical and user expertise on those areas that stand to benefit most from it. In addition, decision analysis highlights specific areas of disagreement, promotes effective communication by precisely defining points for discussion, and provides feedback concerning the importance of any disagreement about the decision being considered.

Above all, the theory is valuable as a vehicle for rigorous, pragmatic interpretation of weighted criteria that permits meaningful aggregation of technical and user judgments. Computerizing the analysis provides real-time response to evaluators concerning the implications and sensitivity of their judgments. Thus the methodology can serve as a catalyst for the group discussion process and thereby enhance productivity. DMJ

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Industry-to-industry international armaments cooperation, phase I—NATO Europe

Office of the Under Secretary of Defense for Research and Engineering, June 1983

In April 1982, the under secretary of defense for research and engineering requested that the Defense Science Board form a task force to examine armaments production cooperation between the U.S. and its allies and to proffer policies and procedures that would enhance industry-to-industry cooperation on defense programs. The task force comprised 12 industry executives and DoD's assistant under secretary for international programs. The group's fact-finding efforts included frank discussions with prominent industrialists from 14 European firms, marking the first-ever DoD-sponsored multinational industrial meeting in Europe. The following is a summary of the task force's phase I report, which addresses cooperation between the U.S. and NATO-Europe; cooperation with Japan will be the subject of a phase II report, to be published soon.

The sustained Soviet arms buildup and the constrained defense budgets of NATO countries underscore the need for effective cooperation among NATO allies in armaments production. Such industrial cooperation affords better utilization of technology and resources, decreases the likelihood of research and development redundancy, and fosters greater interoperability and standardization.

Cooperative industrial efforts traditionally have been the offspring of government-to-government negotiation. However, in the view of the task force, the time has come for industry to take a more active role in formulating such arrangements. Industry can help ensure that these cooperative relationships are based on sound business principles and are likely to benefit the alliance's industrial base.

The feasibility of increased industrial cooperation hinges on a number of factors, including government-imposed impediments, perceived economic benefits, and the motivation and commitment of the principals. Although their interest in establishing cooperative arrangements is similar to that of the U.S., European governments and industrialists remain somewhat wary of such ventures.

Central to their apprehension is the European sentiment that cooperative armaments programs, while beneficial to the NATO defense posture, often are risky business propositions, particularly if the potential market for the item is restricted or highly speculative. American industry is also somewhat reluctant to share its latest technology with prospective competitors. Nonetheless, U.S. firms generally seem to favor the cooperative approach, so long as it makes good business sense and is effectively supported by statute.

The ratio of successes to failures among NATO cooperative ventures is higher than is generally recognized. Many of the successful programs have been high-volume, multinational efforts. These include the Sidewinder, Hawk, F-16, and Sea Sparrow. The failures have been infrequent, but long-remembered. They include curtailment of the U.S. production of the French-German Roland air defense missile system and codevelopment of the British JP 233 airfield attack system.

According to the task force report, improved armaments production cooperation will require that issues be addressed in the following areas:

Policy and commitment. The biggest cloud hanging over the prospect of increased industrial cooperation is uncertainty about the real objectives, policies, and long-term commitment of the United States. Contradictions between policy statements supporting cooperation and subsequent actions cause our European allies to harbor serious doubts about the business sense of entering into cooperative ventures. A clear reaffirmation of policy will help ensure coherent actions by disparate DoD elements and will also encourage U.S. industry to properly respond to that policy.

Proper roles of government and industry. International programs apparently are more likely to succeed if the participating governments set policy guidelines and then delegate program management to the contractors involved. The traditional American concept that industry can do the job alone is not applicable to an international program. In multinational ventures, government and industry must share responsibilities along clearly defined lines, particularly at working levels within the DoD procurement community.

Technology transfer. Although a desired and essential element of industry-to-industry cooperation, technology transfer has yet to overcome a number of obstacles. They derive from fear that U.S. technology will slip into possession of the Warsaw Pact and that the European nations will use this technology to make their products more competitive with those of the U.S. Although these concerns are valid, they do not justify the prevailing level of protection.

The Militarily Critical Technologies List, for example,

which is the controlling document for technology transfers, appears overly restrictive. The same holds true for DoD's interim policy on technology transfer. The final DoD statement on the matter must simplify the approval process, encourage industrial cooperation, and offer strong and effective guidelines for preventing leakage to the Soviets.

Congressional considerations. Despite congressional acknowledgment of the benefits of international cooperation, individual members of Congress often must weigh the economic implications that specific cooperative programs may have for their constituencies. So, while support for international armaments cooperation within Congress may be broad, it is also diffuse and inconsistent. Industry-to-industry cooperation offers perhaps the best alternative to the problems inherent in such a paradox.

DoD organization for armaments cooperation. The current DoD organizational structure is not optimum for administering cooperation-oriented defense assistance. Within DoD, the research and engineering element has the best grasp of the factors impinging on cooperative production efforts, but international security affairs has the largest voice in such matters. To add to the problem, the Defense Security Assistance Agency, which negotiates foreign military sales agreements and is deeply enmeshed in acquisition and logistics, reports to international security affairs. According to the task force, DoD organizational improvements are clearly needed.

Support by U.S. military services. Critical to the implementation and success of cooperative production programs is the support of the individual military services. Although the services are perceived as opponents of such ventures, the individual service chiefs express support for them and for removal of inordinate restrictions on technology transfer. If cooperative programs are to become a truly significant acquisition mode, DoD and the individual services will have to take high-level policy and organizational measures on their behalf.

Types of cooperative programs. Over the last two decades, modes of armaments acquisition cooperation within NATO have ranged from relatively straightforward licensed production to more complicated codevelopment projects. The United States and Europe agree that any of the arrangements or adaptations thereof can be highly effective if they are attractive from a business standpoint. Codevelopment, of course, is the most difficult mode to implement. It calls for maximum technology transfer at a very early stage and requires companies to invest money in a chancy proposition.

Coproduction, on the other hand, has the advantage of a clearly defined product and market. However, it requires considerable investment with little guarantee of follow-on production. The U.S. needs to be sensitive to the special problems that accompany coproduction, while the Europeans must understand that a truly balanced industrial partnership demands adequate investment in research and development.

Offsets within NATO. Boasting defense budgets that have grown by about 2 percent annually since 1970, most European governments are now insisting that their national industries play some role in international defense production. With the U.S.-to-European defense trade balance running at about seven to one, a number of European countries are requiring direct offset arrangements, usually in the form of components manufacture. Moreover, smaller countries are not likely to maintain current armaments spending levels in the absence of appreciable offsets.

Third-country sales. European arms producers have a smaller local market than do U.S. producers, making it necessary for them to capture a share of third-world markets in order to realize economical production runs. Because the United States often refuses to authorize third-country sales of products containing U.S. technology, European manufacturers in turn find it necessary to reject cooperative arrangements and proceed with their own developments. Adding to the problem is the State Department's reluctance to approve third-country sales in advance, thus making any cooperative production venture an uncertain proposition for European participants. Greater U.S. flexibility in giving advance authorization for third-country sales would help remedy the situation. If sensitive technology legitimately precludes such sales, the U.S. and its partners should develop a time-phased release schedule for specified buyers based on an evaluation of the risks involved.

Procurement regulations and practices. The Department of Defense now sells technical data packages and manufacturing rights to foreign governments whose industries compete with U.S. contractors. This practice, which places American firms at a severe disadvantage in dealing with their foreign counterparts, should be curtailed. Instead, the contractors involved should work out the technical and business arrangements required for a collaborative project. Also needed is a revised NATO quality control specification, one that DoD can use in international programs without supplementation.

Second sourcing in Europe. The designation of a licensed production center in Europe as a second source for U.S procurement would provide incentives for our allies to adopt U.S. systems and to participate in

cooperative development programs. Also, European second sourcing would represent a competitive alternative that might lead to lower costs, and Congress should therefore be willing to support legislation to permit the practice. Such an arrangement would be an important step toward an alliance-wide industrial base as proposed by the Nunn-Roth-Glenn amendment to the 1983 Defense Authorization Act.

Failure to establish a proper climate for cooperative armaments production will be detrimental to Western defense industries and to NATO's overall military posture. Certainly, the difficulties of forging such arrangements are real. But with the proper resolve and commitment from government and industry on both sides of the Atlantic, the impediments can be removed, leaving a smoother path to a mutually beneficial end.

Evaluation of the effects of lifting civilian personnel ceilings in DoD industrial fund activities, FY 1983

Office of the Secretary of Defense, March 1, 1984

During FY 1983, DoD carried out a congressionally directed experiment to investigate the consequences of removing civilian personnel ceilings at its commercial-type activities, primarily depots involved in maintaining, repairing, or modifying systems and equipment. The purpose was to determine whether DoD managers could improve the performance and fiscal efficiency of their operations if they had greater authority and flexibility in managing human resources. The test program freed industrial activity managers from traditional manpower constraints and allowed them to use professional discretion in assembling a work force appropriate for the prevailing workload demands.

The experiment proved quite successful despite three factors that qualify the results somewhat. First, ceilings were not removed until the third month of FY 1983. By that time, managers had already developed manpower plans to satisfy anticipated ceilings. Second, in deference to the possibility of a reimposition of ceilings in FY 1984, managers were reluctant to add permanent employees who might have to be discharged later on. And finally, total funded workloads did not increase much between FY 1982 and FY 1983, thus limiting the real need to hire above the previous year's ceiling. Despite these limitations, the test clearly disclosed a prudent stewardship of human resources and curtailment of wasteful, stopgap stratagems for circumventing manpower curbs.

Historically, the imposition of manpower ceilings has stemmed from the belief that payrolls, if left unchecked, will expand beyond a level commensurate with workload. In addition, some view ceilings as a mechanism for forcing managers to be efficient and as a counter to incentives to employ more full-time permanent employees than may be necessary. These incentives, ceiling advocates claim, are by-products of a system that bestows grade and status based on number of employees supervised and appraises performance based on mission accomplishment, not efficiency.

Those who favor ceilings point out the various tools that managers have at their disposal to compensate for personnel constraints. Overtime, contracting out, and temporary and phased hiring are all examples. But while such expedients enable managers to satisfy workload demands and comply with personnel ceilings, they can, in the long run, create an operating climate that is less economical and effective than one unencumbered by arbitrary ceilings. The benefits and cost savings during the FY 1983 experiment demonstrate that removal of year-end personnel ceilings leads to more efficient management of DoD's industrial activities.

Problem areas highlighted by last year's test include the following:

Personnel practices. Over the years, DoD managers have principally used two practices to complete their jobs while complying with year-end ceilings. One entails hiring temporary employees early in the fiscal year and terminating them shortly before year's end. The result is a generally stable and adequate work force most of the year, but pronounced understaffing at the beginning and end, necessitating increased overtime for permanent employees.

In taking a phased hiring approach, another favored tactic, managers develop a hiring plan that allows completion of a disproportionate share of the workload in the second and third quarters of the fiscal year. Thereafter, they phase down the payroll either through attrition or release of temporary employees. But in order to meet year-end ceilings, they sometimes must impose hiring freezes in the third and fourth quarters.

Such cyclical patterns of hiring, releasing, and rehiring impose significant costs. For various reasons, as many as one-third of released employees do not return, making it necessary to train inexperienced people. Also detracting from productivity are the hours that must be